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Effects of Flow Equalization on the Operation and Performance of an Activated Sludge Plant

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16 ABSTRACT

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EFFECTS OF FLOW EQUALIZATION ON THE OPERATION AND PERFORMANCE OF AN ACTIVATED SLUDGE PLANT

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

It provides a documentation of the operation and an evaluation of the impact of flow equalization as applied to a medium-sized municipal wastewater treatment plant.

Francis Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

A plant-scale research program was carried out for more than a year to evaluate the impact of flow equalization on the 14,000 m^3/day (3.7 mgd) upgraded activated sludge plant at Ypsilanti Township, Michigan. Process streams were characterized under both equalized and unequalized flow conditions with respect to BOD, COD, TSS and forms of nitrogen and phosphorus.

The equalization system was effective in leveling influent diurnal flow variations but was limited in its ability to dampen variations in wastewater concentration and mass flux. Some biochemical action apparently occurred in the equalization basin, although BOD removal was marginal and inconsistent. Analysis of secondary effluent indicated that plant performance was similar with and without equalized flow, suggesting that the theoretical advantages of flow equalization may not be achieved in manually controlled plants. An examination of theoretical power costs for equalized and unequalized flow conditions indicated that the use of flow equalization did not result in power cost economies.

This report was submitted in fulfillment of Grant No. S 801985 by Ypsilanti Township under the sponsorship of the U.S. Environmental Protection Agency. Work was subcontracted to Johnson & Anderson, Inc. The report covers the period June 1974 to August 1975, and work was completed as of December 1976.

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ABBREVIATIONS AND SYMBOLS

avg	average
BOD_5	5-day biochemical oxygen demand
cfm	cubic feet per minute
cm	centimeter(s)
COD	chemical oxygen demand
cu	cubic
DO	dissolved oxygen
ft	foot (feet)
F/M	food-to-Microorganism ratio
gal	gallon(s)
gpd	gallons per day
gpm	gallons per minute
kg	kilogram(s)
kw	kilowatt(s)
kwh	kilowatt hour(s)
l	liter(s)
lb	pound(s)
m	meter(s)
mm	millimeter(s)
max	maximum
mgd	million gallons per day
mg	milligram(s)
min	minute(s)
ml	milliliter(s)
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
NH_3-N	ammonia nitrogen

NO_3-N	nitrite + nitrate nitrogen
psi	pounds per square inch
s	second
scfm	standard cubic feet per minute
SOP	soluble orthophosphate (expressed as phosphorus)
SRT	solids retention time
sq	square
SDI	sludge density index
SVI	sludge volume index
TDH	total dynamic head
TKN	total kjeldahl nitrogen (sum of TON and NH_3-N)
TON	total organic nitrogen
TP	total phosphorus
TSS	total suspended solids
VSS	volatile suspended solids

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SECTION I

INTRODUCTION

Most municipal treatment plants experience variations in the quantity and quality of influent wastewater. Such variations occur according to the time of day, day of the week, and season of the year. Their magnitude is primarily a function of the size and characteristics of the sewer system, the degree of infiltration-inflow, and the relative impact of industrial contributors.

Recently, there has been a considerable amount of interest in the use of flow equalization basins to smooth out the diurnal fluctuations of concentration and flow rate at municipal treatment plants. For example, at least three feature articles have appeared in technical magazines since 1976 highlighting the presumed benefits and applications of flow equalization.[1-3] Among the reported advantages are the following:

1. Equalization improves performance of sedimentation basins by leveling hydraulic variations and reducing peak flow rates; in so doing, it permits smaller requisite clarifier sizes in new plant design or increased capacity of existing units.

2. It benefits biological treatment by producing increased uniformity in the concentration and flux of organics and nutrients in the wastewater, as well as more stable retention periods and biomass concentrations in the aeration basin.

3. It simplifies manual and automated control of flow-rate dependent operations, such as chemical feeding, disinfection, sludge pumping, etc.

4. It improves the settleability of wastewater and provides some BOD reduction and odor removal (if aeration is used for mixing in the equalization basin).

5. It provides a point of return for recycling concentrated waste streams, thereby mitigating shock loads to primary settlers or aeration basins.

6. It provides the potential for lowering energy costs by dampening peak power demands for pumping and aeration.

Actual operating experience with flow equalization systems is quite limited and has produced some mixed results. LaGrega and Keenan[4] found that suspended solids removal in a primary settler improved with flow equalization and that the standard deviation of primary effluent data was substantially lower under equalized conditions for the variables tested (BOD, COD, TOC, TSS and VSS). The diurnal variations in these experiments produced a peak-to-average flow rate ratio of less than 1.3. The results of Boon and Burgess[5] were less promising. These authors performed pilot plant studies with parallel activated sludge systems in which one system operated with constant flow and the other with diurnally varying flow at a peaking factor of 3.1. Data obtained failed to show that flow equalization had any significant effect on 24-hour composite BOD removal; however, effluent BOD was found to be more consistent under constant flow conditions. In a plant-scale study, Foess, et al[6] compared the performance of an underloaded plant under sequential periods of equalized and normal flow. They found that the performance of tertiary filters was better when the flow was equalized but that equalization had no discernible effects on the activated sludge system performance.

In activated sludge systems, fluctuating flows have the potential to generate (a) a biological response, wherein the biochemical efficiency of substrate removal might be affected; (b) a biophysical response, in which changes in sludge settleability might occur; and (c) a purely physical response in which the liquid-solids separator might become overloaded at the peak diurnal flow. According to George and Gaudy,[7] the biological response in completely mixed systems becomes significant only after there is a flow rate increase of more than 100 percent. Busby and Andrews[8] showed that both the biological and biophysical effects of diurnal variations can be mitigated by application of one or more available control strategies designed to regulate MLSS

without the need for flow equalization.[8] Thus, the liquid-solids separation step is the one that appears to be the most sensitive to flow rate variations and is the one that was focused on in this study.

The cost-effectiveness of flow equalization is another area of uncertainty. Smith et al[9] and the Ontario Ministry of the Environment[10] have performed work in this area but the reported results were considered by each author to be preliminary in nature. Plant operating data with and without equalization are needed before a final determination of the cost-effectiveness of equalization can be made.

Techniques for designing the equalization basins themselves are fairly well established. In municipal wastewater treatment, the objective is usually to equalize flows rather than concentrations and the conventional mass diagram approach can be used.[11] If concentration dampening is the objective, several analytical methods are available,[12-15] but their focus is on industrial rather than municipal wastes. Modeling of equalization basin performance is generally based on assumptions of complete mixing and conservative (nondegradable) substances. There is a virtual lack of published performance data on equalization basins receiving municipal sewage. The work reported herein will provide information on the magnitude of BOD reductions and other biochemical transformations that may occur across an equalization basin.

[8]Such control strategies include, for example, 1) varying sludge return rate in proportion to influent wastewater rate, 2) varying the recycle flow rate in accordance with the height of the sludge blanket in the clarifier, 3) regulating waste sludge flow rate as a function of sludge blanket height, and 4) using continuously adjusted step-feed contacting patterns.

SECTION II

SUMMARY

A plant-scale research program was carried out for more than a year to evaluate the impact of flow equalization on the operation and performance of a conventional activated sludge plant. The studies were conducted at the Ypsilanti Township, Michigan treatment plant, an upgraded 14,000 m^3/day (3.7 mgd) facility containing an "in-line" equalization basin with a capacity of 2377 m^3 (628,000 gal). The average daily plant flow was about 15,140 m^3/day (4 mgd) while peak hourly flows were around 22,700 m^3/day (6 mgd).

Daily 24-hr composite samples were collected from process streams before and after equalization and after final clarification; in addition, a more rigorous sampling and analysis program was conducted during a few days each month in which bi-hourly composite samples were collected and analyzed. For comparative purposes, short-term data were obtained on plant performance after taking the equalization basin out of service. Special studies were also conducted in which the plant was stressed in both the equalized and unequalized modes by selectively removing final clarifiers from service, thereby increasing the overflow rate in the remaining clarifiers.

The equalization system functioned in a reliable manner throughout the study and was highly effective in leveling influent diurnal flow variations and providing a uniform daily flow rate to the activated sludge process. The degree of concentration and mass dampening achieved was much more limited and appreciable variability of strength remained in the equalized stream. Statistical analysis of the data revealed that reductions in the variances of BOD_5, TSS and other constituents such as COD, SOP, TP, and NH_3-N across the equalization basin were in the range of about 20 to 80 percent based on concentration and 45 to 95 percent based on mass.

Comparison of mass flux data into and out of the equalization basin for TSS, BOD, COD, SOP, TP, NH_3-N and TON indicated that some biochemical action occurred in the basin. There was a definite increase in suspended solids across the basin but BOD_5 removal was marginal and inconsistent.

Analysis of secondary effluent indicated that the effects of flow equalization were apparently less important in determining effluent quality than the effects of other operational variables such as organic loading intensity, sludge settleability, wind and density currents, recycle rate, sludge blanket height, chemical dose (for P precipitation), etc. This was evidenced by a) the similar removals of TSS and BOD_5 that were obtained with and without equalized flow, and b) the lack of sensitivity of final clarifier performance to diurnal variations in overflow rate for overflow rates up to 37 $m^3/day/m^2$ (1400 gpd/sq ft).

An analysis of costs showed that the capital costs associated with conversion of existing digesters to equalization basins were only about 25% of those that would have been experienced with construction of new equalization facilities. An analysis of theoretical power costs for equalized and unequalized flow conditions indicated no power cost economies occurred with flow equalization. Reductions in demand charges were slightly less than increased energy charges during equalized flow periods.

SECTION III

CONCLUSIONS

1. Existing digesters, which might otherwise be abandoned in a plant expansion, can be converted to workable equalization basins (Section VIII, p. 22).

2. At the Ypsilanti Township treatment plant, the use of flow equalization does not add measurably to overall labor requirements for the plant (Section VIII, p. 54).

3. The degree of concentration and mass dampening will be limited in in-line equalization basins which are sized to level only diurnal flow variations, as evidenced by the reductions in variance of waste parameters across the equalization basin in these studies. Variance reductions for TSS, BOD_5, COD, SOP, TP, NH_3 and TON ranged generally from 20 to 80 percent for concentration and 45 to 95 percent for mass (Section VIII, p. 30).

4. Equalization produces changes in the waste as a result of biochemical action within the basin but such changes are small. For example, BOD_5 reduction across the equalization basin averaged only about 7 percent, while some growth of biomass occured, causing an increase in TSS of about 9 percent (Section VIII, p. 30).

5. Performance of the Ypsilanti Township plant was very similar under both equalized and normal flow conditions, even when the final clarifiers were hydraulically stressed to overflow rates as high as 57 $m^3/day/m^2$ (1400 gpd/sq ft) (Section VIII, pp. 41-48).

6. The theoretical advantages of flow equalization were not achieved in this manually controlled activated sludge treatment plant operated at and above conventional design loading ranges. It is concluded that any beneficial effects of flow equalization were overshadowed or neutralized by a) suboptimal application of control schemes for the biological process, and b) a lack of sensitivity of final clarifier performance to normal variations in flow rate (Section VIII, pp. 44-48).

7. The covered equalization basin at Ypsilanti Township had no significant effect on wastewater temperature; basin influent and effluent readings were generally within 1°C (Section VIII, p. 48).

8. In the Ypsilanti Township equalization basin, the aeration requirements for providing complete mixing are greater than for maintaining aerobic conditions. The minimum level of aeration for preventing solids deposition was about 7.5×10^{-6} $m^3/min/l$ (1.0 cfm/1000 gal) of storage (Section VIII, p. 49).

SECTION IV

RECOMMENDATIONS

The results of the work reported herein indicate that while flow equalization does provide certain benefits, it is by no means a panacea for improving the performance of activated sludge plants. Thus, engineers should not specify the use of flow equalization indiscriminantly but rather should critically evaluate its merits on a case-by-case basis.

If additional research related to flow equalization is undertaken, the following deserve further consideration:

1. The variation in percentage removals obtained by primary clarifiers and effluent suspended solids carryover by secondary clarifiers should be evaluated for different intensities of flow and strength variations.

2. The effects of flow equalization on the requisite sizes of downstream treatment units should be determined.

3. The relative importance of flow equalization versus concentration and mass equalization should be evaluated.

4. The limitations of equalizing diurnal flow variations while permitting day-to-day, weekly, and seasonal variations to continue should be studied.

5. The effects of flow equalization on chemical treatment processes, such as phosphorus removal, need further clarification.

SECTION V

EXPERIMENTAL PLAN

The experimental program was undertaken to demonstrate the impact of flow equalization on the operation and performance of a conventional activated sludge plant treating municipal sewage under practical operating conditions. In general, the approach was to compare the relative process performance of the plant under consecutive periods of equalized and unequalized operation. A side by side comparison of equalized and unequalized activated sludge systems was also possible in that there were two independent parallel plants on the site; however, this comparison was of limited value because the plants did not receive the same feed wastewater. The specific program objectives were the following:

1. Demonstration of the applicability of employing flow equalization in upgrading an existing activated sludge treatment plant.

2. Characterization of the effects of flow equalization on the concentration and mass of organics and nutrients in the wastewater.

3. Comparison of process treatment effectiveness and economics of equalized and unequalized-flow activated sludge systems operating under conventional organic loadings (0.2-0.5 g/g-day) and aeration detention times (3-6 hours based on raw flow), and moderate to high final clarifier overflow rates of 29-37 $m^3/day/m^2$(700-1400 gpd/sq ft).

4. Evaluation of overall plant operation with respect to the relative ease or difficulty of operating in the equalized versus the unequalized mode.

These studies were conducted using the Ypsilanti Township, Michigan, Municipal Treatment Plant with the cooperation of Township officials and the treatment plant staff. The existing Ypsilanti Township treatment facility comprises two parallel activated sludge plants. Plant No. 1 was completed in 1942 with a design flow of 9,460 m^3/day (2.5 mgd), but was upgraded to treat 14,000 m^3/day (3.7 mgd) and equipped with flow equalization in 1973. Plant No. 2 was completed in 1963 and designed for an average daily flow of 14,350 m^3/day (3.8 mgd). As data presented here will illustrate, the average daily flow of each plant is about 14,000 m^3/day (3.7 mgd) with hourly flow variations from 5,680 to 22,700 m^3/day (1.5 to 6.0 mgd). The BOD strength of the incoming wastewater to each plant averages about 200 mg/l with hourly variations from 90 to 400 mg/l. Feed wastewater to each plant is predominately of domestic origin but contains a representative portion (about 25 percent) of industrial waste.

The experimental plan was carried out over approximately a 14-month period. Essentially three modes of operation of Plant No. 1 were studied: i) equalized flow at approximately the design capacity of the plant; ii) equalized flow under hydraulically stressed conditions in the final clarification step; and iii) unequalized (normal diurnal) flow conditions. No changes were made in the operation of Plant No. 2 throughout the study; this plant had no direct role in the research other than serving as a general control.

The program objectives and plan described in the preceding reflect some changes which were made during the course of the project. Originally, it was hoped to modify the influent works so that both plants received the same wastewater; however, budgetary limitations did not permit these modifications to be made. It was also hoped to modify the influent works so that the diurnal flow variations to Plant No. 1 could be magnified; these modifications were also not implemented because of lengthy delays in equipment delivery.

SECTION VI

PLANT AND EQUIPMENT DESCRIPTION

Plant No. 1

General Description

The wastewater treatment complex in Ypsilanti Township, Michigan contains two independent treatment plants (See Figure 1). Most of the experimental work was performed on Plant No. 1, a plug-flow activated sludge facility equipped for flow equalization and ferric chloride and polymer addition to the aeration basin effluent. The plant has a design treatment capacity of 14,000 m^3/day (3.7 mgd) based on a final clarifier overflow rate of 32.6 $m^3/day/m^2$(800 gpd/sq ft). There are no primary clarifiers at Plant No. 1.

Raw sewage from a portion of the Ypsilanti Township collection system enters a pumping station (Snow Road Lift Station) located remotely from Plant No. 1. The sewage is pumped directly to the equalization tanks and then is re-pumped to a bar rack channel. Gravity flow occurs through the remaining plant processes which consist respectively, of aeration, final settling, and disinfection. The equalization tanks can be by-passed by pumping raw sewage from the pumping station directly to the bar rack channel.

Equalization System

The equalization system at this plant is the in-line type. Two existing digesters were converted to equalization tanks, providing an effective retention capacity of 2,362 m^3 (624,000 gal) which is about 17 percent of the average daily design flow. Figure 2 depicts pertinent features of the tanks.

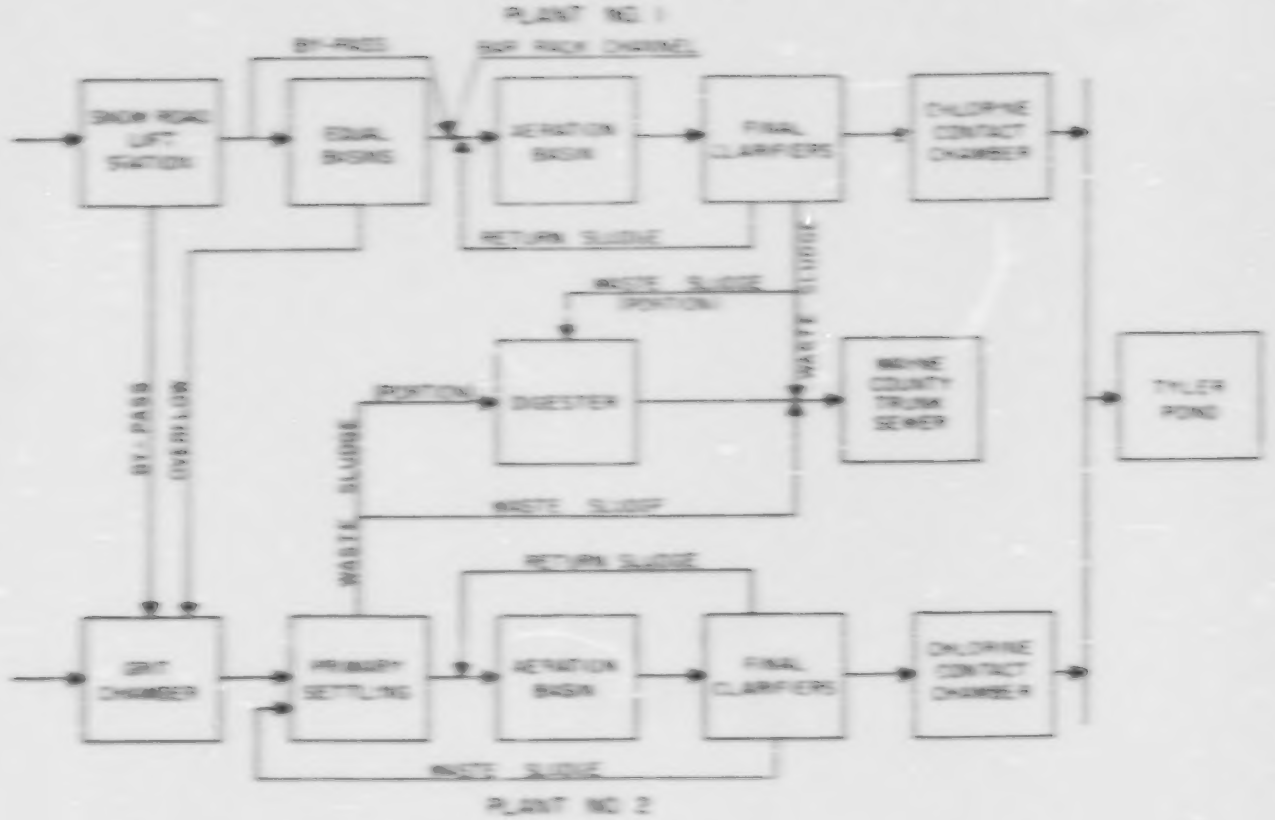
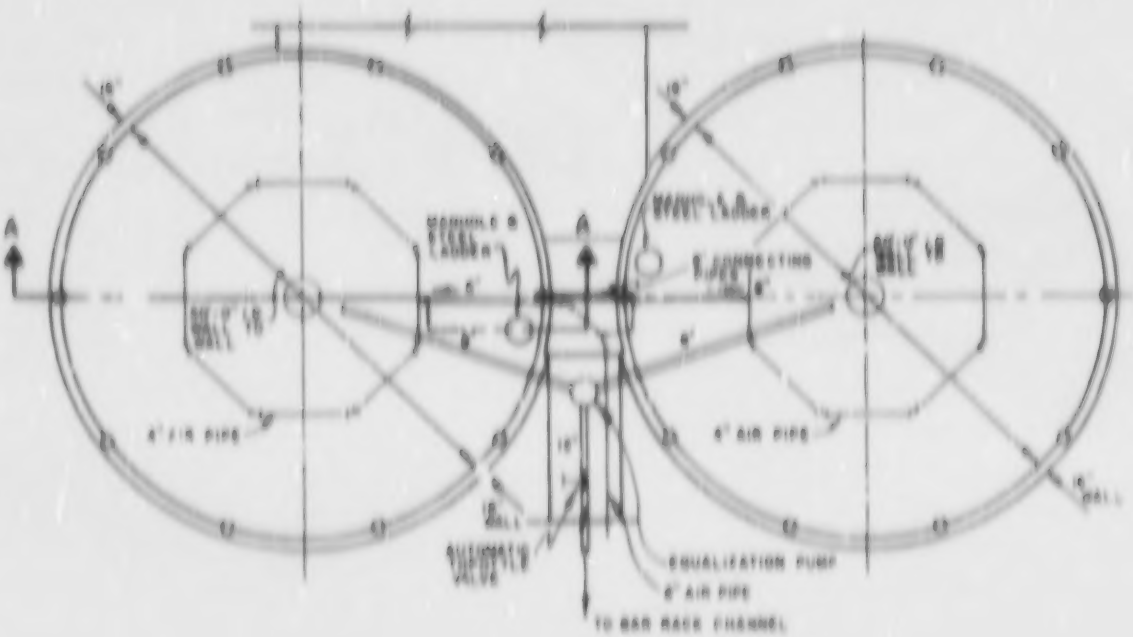


FIGURE 1 - Flow schematic of Ypsilanti Township wastewater treatment facilities.



PLAN

SECTION A-A

FIGURE 2 - Plan and section of the Ypsilanti Township equalization basins (Note: in. x 2.54 = cm; ft x 0.3048 = m).

The process flow rate out of the equalization tanks is regulated by precisely maintaining the desired liquid level in the plant bar rack channel. This is achieved by a liquid level controller in the channel tied to a throttling valve located directly after the equalization pump. Thus, if the liquid elevation in the channel begins to vary from the preset level, the throttle valve is automatically opened or closed to maintain the desired level. There is only one equalization pump; it has a capacity of 126 l/s (2000 gpm) at a TDH of 9.1 m (30 ft).

Air is supplied to the equalization tanks by a single positive displacement compressor with a rated capacity of 25.5 m^3/min (900 scfm) at 0.84 kg/sq cm (12 psig) of head. A second compressor of the same size is available as a stand-by unit. Valves and meters were installed so that the air flow to each equalization tank can be regulated and measured independently. Air injection is accomplished through Walker Process "Mono-Sparg 3/32" nozzles located 0.6 m (2 ft) from the bottom of the tanks.

Aeration Basins --

There are four rectangular aeration tanks which operate in parallel. Each tank is baffled into four compartments for better plug flow characteristics. The total volume of the tanks is 3,510 m^3 (927,500 gal) which results in 6.0 hrs of mixed-liquor detention time based on 14,000 m^3/day (3.7 mgd) feed flow. Each tank is 7.6 m (25 ft) wide, 30.5 m (100 ft) in length, and 4.6 m (15 ft) deep.

Air is normally supplied from one 84.0 m^3/min (3000 scfm) positive displacement blower. A second blower of the same size is also available when needed. The compressed air is diffused into the mixed-liquor through Walker Process "Duo Spray 3/32" nozzles. The air pipes to each nozzle header contain valves for balancing the air flow. Ferric chloride and polymer solutions are added to the outlet trough of the aeration basins for precipitation of phosphorus, with the feed rate being automatically paced to flow rate.

Final Settling Tanks --

Eight final clarifiers receive the aeration tank effluent. Four of the tanks are 4.3 m (14 ft) wide and 18.3 m (60 ft) long with a 3.7 m (12 ft) water depth. The remaining four

are 2.6 m (8.5 ft) wide and 18.3 m (60 ft) long with a 3.7 m (12 ft) water depth. The final 5.5 m (18 ft) of each tank contains a bank of effluent weirs. Assuming that half of the weir bank area is ineffective for settling, the total settling area of the tanks is 426.6 m^2 (4,590 sq ft). Based on an overflow rate of 32.6 m^3/day/m^2 (800 gpd/sq ft) the design flow rate is 14,000 m^3/day (3.7 mgd).

Settled activated sludge is moved to collection hoppers in each tank by mechanical scrapers. It then flows by hydrostatic pressure to sludge draw-off wells. From the draw-off wells the sludge is pumped to the aeration basin influent. Excess sludge is wasted as required to maintain a constant concentration of activated sludge in the aeration basin. Waste sludge is pumped to the plant digester or directly to the Wayne County trunk sewer (the digester has sufficient capacity to treat only about 20 percent of the sludge generated). There are two return sludge pumps, each with a capacity of 63.1 l/s (1000 gpm) at 9.1 m (30 ft) TDH, and two waste sludge pumps, each with a capacity of 6.3 l/s (100 gpm). The system is designed so that return sludge pumping rates are approximately proportional to the plant flow rate. Return sludge rates for each settler can also be independently controlled to meet process conditions at any given time. Piping of the final settlers permits any one or more of the eight units to be individually taken out of service.

The reason for the two different sizes of final settling tanks is that half of the settlers were originally used as primaries. They were converted to final settlers in the upgrading program just prior to this study. By converting primary settlers to secondary settlers and by converting existing digesters to equalization tanks, the plant capacity was increased from 9,460 m^3/day (2.5 mgd) to 14,000 m^3/day (3.7 mgd) without the addition of any new structures.

Flow Metering

Plant influent flow is measured by a magnetic flow meter at the influent pumping station. There is digital output of the totalized flow at the treatment plant but no continuous recording of flow rate. Plant effluent flow is measured by a rectangular weir and is recorded on circular charts. Agreement between the influent and effluent meters is usually within 10 to 20 percent. Some or all of the differences in corresponding daily readings between the influent and effluent meters can be attributed

to net accumulation or release of stored wastewater in the equalization basins. Instances were also observed when the equalization tanks overflowed; since the overflow goes to Plant No. 2, it would not be recorded by the Plant No. 1 effluent meter.

Return sludge flow rate is measured with a magnetic flow meter and continuously recorded. Waste sludge flow rate is not independently measured due to interconnection of the waste sludge piping systems of Plants No. 1 and No. 2.

Plant No. 2

Plant No. 2 treats wastewater from three gravity lines which serve those portions of the Ypsilanti Township system not served by Plant No. 1. The treatment system comprises comminution, grit removal, primary sedimentation, aeration, final sedimentation, and disinfection. Ferric chloride is added continuously to the aeration basin effluent for phosphorus removal. The design treatment capacity is 14,380 m^3/day (3.8 mgd) based on an overflow rate of 32.6 m^3/day m^2 (800 gpd/sq ft).

Plant No. 2 contains two rectangular primary sedimentation tanks with a total effective surface settling area of 452 m^2 (4,860 sq. ft). Waste activated sludge is added to the primary tank influent and combined primary-and-secondary sludge is therefore withdrawn from the tanks and disposed with the sludge from Plant No. 1 (See Figure 1).

The effluent from the primary tanks flows to two rectangular aeration tanks. The total volume of the tanks is 4,405 m^3 (1,163,900 gal) resulting in 7.3 hrs of mixed-liquor detention time based on 14,380 m^3/day (3.8 mgd) feed flow.

Two rectangular final settlers receive the effluent from the aeration basins. The settlers have a total effective surface settling area of 440 m^2 (4,740 sq ft).

SECTION VII

METHODS AND PROCEDURES

Concurrent with the final stages of the upgrading program at Ypsilanti Township Plant No. 1, an analytical laboratory was established about 4 miles from the plant. This laboratory was equipped with automated equipment and instrumentation for simultaneously performing routine analyses on a high volume of samples. It was intended that this laboratory supplement the treatment plant laboratory capability by providing analyses on samples collected on week-ends and holidays and during periods of intensive monitoring of plant operation and performance.

Sampling and Analysis

Daily Samples --

The normal daily sampling and analysis were performed by the treatment plant staff except on week-ends and holidays when they were performed by project personnel. Daily sampling was carried out throughout the course of the work. Table I shows the various analytical measurements made on samples collected from the different plant locations.

Daily composite samples were collected for a 24-hour period beginning at 7:00 a.m. each day to conform with previous plant practice. The samples were composited by mixing equal 100 ml volumes of 12 grab samples collected every 2 hours during the 24-hour period; it was not possible with constraints on manpower and budget to flow proportion these samples. Grab samples of mixed-liquor were taken once per day at 9:00 a.m. from the aeration basin effluent troughs of each plant.

TABLE I

DAILY SAMPLES - COLLECTION LOCATIONS, SAMPLE TYPES, AND PARAMETERS ANALYZED

Parameter	Wastewater	Equalization Tank Effluent[a]	Primary Settler Effluent[b]	Mixed-Liquor	Final Settler Effluent
BOD_5	C[c]	C	C	-[d]	C
TSS	C	C	C	G[d]	C
VSS	C	C	C	G	C
TP	C	C	C	-	C
Temp.	G	G	G	-	-
pH	C	-	-	-	G
SVI	-	-	-	G	-
D.O.	G	G	G	G	G

[a]Plant No. 1 only
[b]Plant No. 2 only
[c]Composite sample (C) comprised of twelve bihourly grab samples; composite samples collected daily
[d]One grab sample (G) analyzed daily

Bi-hourly Samples --

On several days each month, bihourly samples were collected by project personnel and analyzed individually rather than composited into one daily sample. The bihourly samples were usually analyzed for BOD_5, TSS, COD, SOP, TP, NH_3-N, TON, and sometimes NO_3-N. Table 2 gives the dates and plant locations that bihourly samples were collected and analyzed.

Analytical Methods

Analytical methods used in the work are described individually below. All methods were verified by running EPA standard samples.

Dissolved Oxygen --

Dissolved oxygen measurements were performed with a membrane electrode. Comparison tests using the azide modification of the Winkler titration method described in Standard Methods[16] were run during the course of the work to assure consistent results.

BOD_5 --

Determinations for BOD_5 were performed by the standard dilution method,[16] using the previously mentioned D.O. membrane electrode. Glucose - glutamic acid solution with known BOD_5 was analyzed with the samples to insure quality control.

Total Suspended Solids --

Total suspended solids measurements were made using the standard gravimetric technique.[16] Gooch crucibles were used to collect the residue.

COD --

Analyses of COD were performed according to Standard Methods[16] using the dichromate reflux method.

TABLE 2

BIHOURLY SAMPLES - COLLECTION DATES AND LOCATIONS
SAMPLE TYPES AND PARAMETERS ANALYZED

Day on which Bihourly Samples were Collected[b]	Sampling Location[a]
June 5, 8, 11, 14, 17, 20, 23 (1974)	1A, 1B
July 10, 13, 16, 19, 22, 25, 28	1A, 1B
Aug 6, 7, 16, 19, 22, 25	1A, 1B, 1C
Sept 11, 12, 13, 14, 15, 16, 17	1A, 1B, 1C
Oct 14, 15, 16, 17, 18, 19, 20	1A, 1B
Nov 12, 13, 14, 15, 16, 17, 18	1A, 1B
Dec 12, 13, 14, 15, 16, 17, 18	1A, 1B
Jan 12, 13, 14, 15, 16, 17, 18 (1975)	1A, 1B, 1C
Feb 7, 8, 9, 10, 11	1C, 2A, 2B, 2C
Mar 10	1A, 1B, 1C, 2A, 2B, 2C
Mar 17, 18	1A, 1B, 1C
Apr 14, 15, 16, 17	1A, 1B, 1C
May 18, 19, 20, 21, 22	1A, 1C, 2A, 2B, 2C
June 3, 4, 5, 10, 11, 12	1A, 1C
June 30; July1, 2, 29	1A, 1B, 1C, 2A, 2B
Aug 5, 6	1A, 1B, 1C

[a] 1A - Plant No. 1, Influent Wastewater
1B - Plant No. 1, Equalization Tank Effluent
1C - Plant No. 1, Final Settler Effluent
2A - Plant No. 2, Influent Wastewater
2B - Plant No. 2, Primary Settler Effluent
2C - Plant No. 2, Final Settler Effluent

[b] Bihourly samples comprised of one grab sample collected every 2 hours. In general, bihourly samples were analyzed for BOD_5, TSS, COD, SOP, TP, NH_3-N, and TON.

Total Kjeldahl Nitrogen and Total Organic Nitrogen --

Analysis of wastewater samples for total kjeldahl nitrogen was done according to the kjeldahl procedure in Standard Methods.[16] Total organic nitrogen was obtained by subtraction of NH_3-N from total kjeldahl nitrogen.

Ammonia --

Ammonia analyses were performed with the Technicon Auto Analyzer II using the phenol-hypochlorite procedure described by Technicon.[17] All samples were filtered through 0.45 micron membrane filters prior to analysis to remove particulate matter.

Total Phosphorus and Soluble Orthophosphate --

Phosphorus analyses were performed with the Technicon Auto Analyzer II using the colorimetric ascorbic acid reduction method.[18] Some analyses were also performed manually using the vanadate colorimetric determination of orthophosphate as described in Standard Methods.[16] To obtain total phosphorus, the persulfate digestion method was employed on an aliquot of the sample to convert all phosphorus to the ortho form. Soluble orthophosphate was determined by performing the colorimetric procedure directly after filtration of an aliquot of the sample through a 0.45 micron filter.

Nitrite and Nitrate Nitrogen --

These analyses were run by an automated procedure using the Technicon Auto Analyzer II.[18] All samples were initially filtered through a 0.45 micron membrane filter for removal of suspended solids. The automated procedure utilized cadmium reduction of the nitrate and subsequent diazotization of the nitrite for color development.

Data Reduction

Raw data were tabulated and preliminarily analyzed on a monthly basis throughout the project. At the end of the experimental work, all data were computationally reduced using a CDC Cyber 76 computer. Special programs were written to analyze and reduce the data to meaningful form. A listing of the data may be found in the Appendix.

SECTION VIII

RESULTS AND DISCUSSION

Equalization System Equipment Performance and Reliability

The equalization system installed at the Ypsilanti Township Treatment Plant has been described earlier in this report. Although this system was designed utilizing two existing sludge digestion tanks as equalization basins, with a strong emphasis on minimizing cost, the system functioned in a highly reliable manner during and subsequent to the periods of operation described herein. Maintenance and service for the system were minimal and no major modifications were required after the initial installation.

Operation and control of the equalization system was performed entirely by regular treatment plant personnel with no unusual attention required for reliable operation. In fact, the system typically operated fully automatically with no need for manual attention other than routine surveillance. Throughout the study, there was no need to by-pass the equalization basins due to failure of any of the system components, including the equalization pump, air compressors, and controls.

The only problem experienced with the system was occasional overflowing of the equalization basin. This occured when the plant flow rate was exceptionally high over a 24-hour period, preventing normal emptying of the tank at night. The overflows were directed to Plant No. 2 so that the equalized flow pattern in Plant No. 1 would not be affected. In a typical situation the overflows would have to be added back to the plant flow, thereby rendering the equalization system ineffective for the duration of the overflows.

Flow, Concentration and Mass Equalization

The Ypsilanti Township equalization system is highly effective in leveling influent diurnal flow variations and providing a uniform daily flow rate to the activated sludge process. Plant flow charts typically show a constant flow rate throughout each day. Because the equalization system was designed to level flow variations only within a given day, the day-to-day, weekly, and seasonal flow variations through the plant were not affected.

Although hourly flow equalization was reliably achieved, the degree of concentration and mass dampening was limited. Tables 5-6 show concentrations of TSS, BOD_5, COD, SOP, TP, NH_3, and TON in both the raw and equalized wastewater streams during ten periods of bihourly testing.[a] Also shown in each instance are the variance, standard deviation and coefficient of variation (standard deviation divided by the mean) of the concentration values (See Appendix). The data show that the equalization basin reduced the diurnal variability of waste strength by 20 to 80 percent for most of the parameters, as measured by the variance.

Typical data illustrating concentration leveling effected by the equalization basin for a 72-hour period are presented in Figure 3. Concentrations of various constituents are plotted as a function of time for both the raw wastewater and the equalized flow. As shown, the equalization system somewhat reduced the diurnal variability of waste strength and lowered the maximum concentrations of waste parameters. However, it is also clear that appreciable variability of strength remained in the equalized stream.

The degree of mass dampening that occurred in the Ypsilanti Township equalization basin was much greater than the concentration dampening. Mass flow values of the various parameters for both the raw wastewater and the equalization basin during the bihourly testing periods are listed in Table 7. Also shown for each parameter are the variance, standard deviation, and coefficient of variation of the mass flow values. Computations show that the reductions in the variance of the mean mass flow of each

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[a]Only periods in which 3 or more consecutive days of data were collected are presented for analysis.

TABLE 3

PERFORMANCE OF PLANT NO. 1
DURING PERIODS OF BIHOURLY TESTING

(Average Over Period Based on Bihourly Values)

Parameter	Statistical Property	10/15 to 10/17 1974	11/13 to 11/15 1974	12/12 to 12/14 1974	1/13 to 1/15 1975	2/17 to 2/19 1975	3/13 to 3/15 1975	4/16 to 4/18 1975	5/13 to 5/15 1975	6/18 to 6/20 1975	8/20 to 8/22 1975
Raw Wastewater Flow, 100 gpm	Mean Variance Std. Dev. Coef. Var.	0.333 0.013 0.115 0.35	0.410 0.009 0.095 0.23	0.401 0.007 0.085 0.21	0.333 0.007 0.082 0.25	*	0.393 0.003 0.056 0.14	0.429 0.003 0.056 0.13	0.375 0.003 0.056 0.15	0.393 0.006 0.076 0.19	*
TSS in Raw Wastewater, mg/l	Mean Variance Std. Dev. Coef. Var.	184 1 0.98	173 1 0.93	168.71 1.05	178 1 0.91	163 1 0.88	172 1 0.92	178 1 0.93	188 1 0.95	178 1 0.93	183 1 0.93
TSS in Sedimentation Basin Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	114 1 0.99	107 1 0.93	101 0.91	118 1 0.85	103 1 0.84	109 1 0.91	*	*	*	128 1 0.87
TSS in Final Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	*	*	*	6.5 0.73	6.5 0.74	11.0 0.91	4.3 0.58	4.4 0.58	6.5 0.77	6.5 0.69
BOD5 in Raw Wastewater, mg/l	Mean Variance Std. Dev. Coef. Var.	140 1 0.98	133 1 0.93	130 0.89	137 1 0.96	126 1 0.90	135 1 0.93	133 1 0.93	145 1 0.96	137 1 0.93	138 1 0.94
BOD5 in Sedimentation Basin Effluent mg/l	Mean Variance Std. Dev. Coef. Var.	101 1 0.78	116 1 0.92	103 0.93	101 0.96	114 1 0.77	108 1 0.88	*	*	*	113 1 0.77
BOD5 in Final Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	*	*	*	4 0.97	5 0.99	8 1.06	3 0.93	3 0.93	4 0.96	3 0.88

* Raw data not in this report computation
† Bihourly composite values

TABLE 9

PERFORMANCE OF PLANT NO. 1 DURING PERIODS OF BIHOURLY TESTING

(Average Over Period Based on Bihourly Values)

Parameter	Statistical Property	10/15 to 10/18 1974	11/13 to 11/16 1974	11/21 to 11/24 1974	1/13 to 1/16 1975	3/17 to 3/18 1975	4/16 to 4/17 1975	5/18 to 5/20 1975	6/3 to 6/5 1975	6/10 to 6/12 1975	6/30 to 7/1 1975
COD in Raw Wastewater mg/l	Mean Variance Std. Dev. Coef. Var.	67,000 260 0.38	56,000 130 0.20	56,000 190 0.34	61,000 190 0.31	19,000 120 0.56	16,000 110 0.63	18,000 120 0.60	*	*	*
COD in Aquaculture Basin Effluent mg/l	Mean Variance Std. Dev. Coef. Var.	1,600 61 0.13	1,700 66 0.17	10,000 190 0.34	19,000 110 0.61	1,900 83 0.18	1,900 79 0.16	*	*	*	*
COD in Final Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	*	*	*	*	*	*	53 0.37	*	*	*
BOD in Raw Wastewater, mg/l	Mean Variance Std. Dev. Coef. Var.	3,3 1.8 0.41	3,3 1.8 0.41	3,3 1.1 0.33	3,3 1.1 0.33	4,0 0.43 0.16	3,3 1.8 0.44	4,1 0.66 0.18	3,3 1.8 0.39	3,3 1.8 0.41	3,3 1.8 0.39
BOD in Aquaculture Basin Effluent mg/l	Mean Variance Std. Dev. Coef. Var.	3,3 1.8 0.38	3,3 1.8 0.38	3,3 1.1 0.33	3,3 1.8 0.38	3,3 0.17 0.13	3,3 0.53 0.24	*	*	*	3,3 0.53 0.18
BOD in Final Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	*	*	*	*	*	3,3 0.53 0.24	3,3 0.53 0.17	3,3 0.53 0.19	3,3 0.53 0.18	3,3 1.8 0.39

*Insufficient data available
**Aquaculture basin not in service
***No final effluent samples taken

TABLE 3

PERFORMANCE OF PLANT NO. 1 DURING PERIODS OF BIHOURLY TESTING

(Average Over Period Based on Bihourly Values)

Parameter	Statistical Property	10/15 to 10/30 1974	11/12 to 11/26 1974	12/10 to 12/24 1974	1/7 to 1/21 1975	2/4 to 2/18 1975	3/18 to 4/1 1975	4/15 to 4/29 1975	5/13 to 5/27 1975	6/10 to 6/24 1975	7/8 to 7/22 1975
Ammonia Nitrogen (as NH_3) in Raw Wastewater, mg/l	Mean Variance Std. Dev. Coef. Var.	17.2 11.9 3.5 0.20	15.0 15.0 3.9 0.27	15.7 15.0 3.9 0.25	12.2 8.3 2.9 0.23	11.8 3.8 2.0 0.17	11.3 3.3 1.8 0.16	11.8 3.0 1.7 0.15	11.8 5.3 2.3 0.20	11.5 3.3 1.8 0.16	10.7 2.7 1.6 0.15
Ammonia Nitrogen (as NH_3) in Equalization Basin Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	13.9 5.0 2.2 0.16	13.1 5.1 2.3 0.18	12.5 9.3 3.0 0.24	11.8 3.8 1.9 0.17	11.5 1.3 1.1 0.10	11.0 3.1 1.8 0.17	b b b b	b b b b	b b b b	9.9 2.0 1.4 0.15
Ammonia Nitrogen (as NH_3) in Final Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	a a a a	a a a a	a a a a	a a a a	a a a a	3.8 3.0 1.7 0.45	3.7 2.8 1.7 0.46	3.5 2.5 1.6 0.45	3.5 2.5 1.6 0.46	3.5 2.5 1.6 0.45
TKN in Raw Wastewater, mg/l	Mean Variance Std. Dev. Coef. Var.	19.8 11.2 3.3 0.16	19.5 15.0 3.9 0.20	21.5 9.3 3.0 0.14	21.6 8.7 2.9 0.13	21.3 7.8 2.8 0.13	21.4 9.4 3.1 0.14	21.3 8.3 2.9 0.13	a a a a	a a a a	a a a a
TKN in Equalization Basin Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	17.2 7.2 2.7 0.15	17.0 7.3 2.7 0.16	17.2 7.3 2.7 0.16	17.0 9.3 3.0 0.17	17.0 5.8 2.4 0.13	17.1 8.4 2.9 0.17	a a a a	a a a a	a a a a	a a a a
TKN in Final Effluent, mg/l	Mean Variance Std. Dev. Coef. Var.	a a a a	a a a a	a a a a	a a a a	a a a a	a a a a	7.1 1.8 1.3 0.17	a a a a	a a a a	a a a a

[a] Parameter not analyzed
[b] Equalization basin out of service
[c] No final effluent samples taken

TABLE 6

PERFORMANCE OF PLANT NO. 1 DURING PERIODS OF BIHOURLY TESTING

(Average Over Period Based on Bihourly Values)

Parameter	Statistical Property	10/13 to 10/14 1974	11/13 to 11/14 1974	12/12 to 12/13 1974	1/13 to 1/14 1975	2/17 to 2/18 1975	3/18 to 3/19 1975	4/15 to 4/16 1975	5/13 to 5/14 1975	6/10 to 6/11 1975	7/7 to 7/8 1975
TP in Raw Wastewater, mg/l	Mean	8.2	9.0	8.8	8.5	7.8	8.3	7.5	7.8	7.8	8.1
	Variance	0.6	1.0	1.1	2.0	0.56	1.3	0.5	0.8	1.1	0.9
	Std. Dev.	0.8	1.0	1.1	1.4	0.8	1.1	0.7	0.9	1.1	0.9
	Coef. Var.	0.10	0.10	0.13	0.17	0.10	0.13	0.10	0.12	0.14	0.11
TP in Secondary Effluent, mg/l	Mean	0.8	0.6	0.9	1.0	0.8	0.8	--	--	--	1.0
	Variance	0.0	0.1	0.1	0.0	0.06	0.03	--	--	--	0.2
	Std. Dev.	0.2	0.3	0.3	0.2	0.2	0.2	--	--	--	0.4
	Coef. Var.	0.14	0.14	0.17	0.09	0.08	0.11	--	--	--	0.14
TP in Final Effluent, mg/l	Mean	--	--	--	--	0.8	0.8	0.7	0.7	0.8	1.0
	Variance	--	--	--	--	0.0	0.0	0.02	0.03	0.03	0.07
	Std. Dev.	--	--	--	--	0.2	0.2	0.15	0.2	0.2	0.3
	Coef. Var.	--	--	--	--	0.09	0.22	0.20	0.19	0.21	0.28

--Parameter not analyzed.
[a]Sedimentation basin out of service
[b]TP final effluent assay = 0 taken

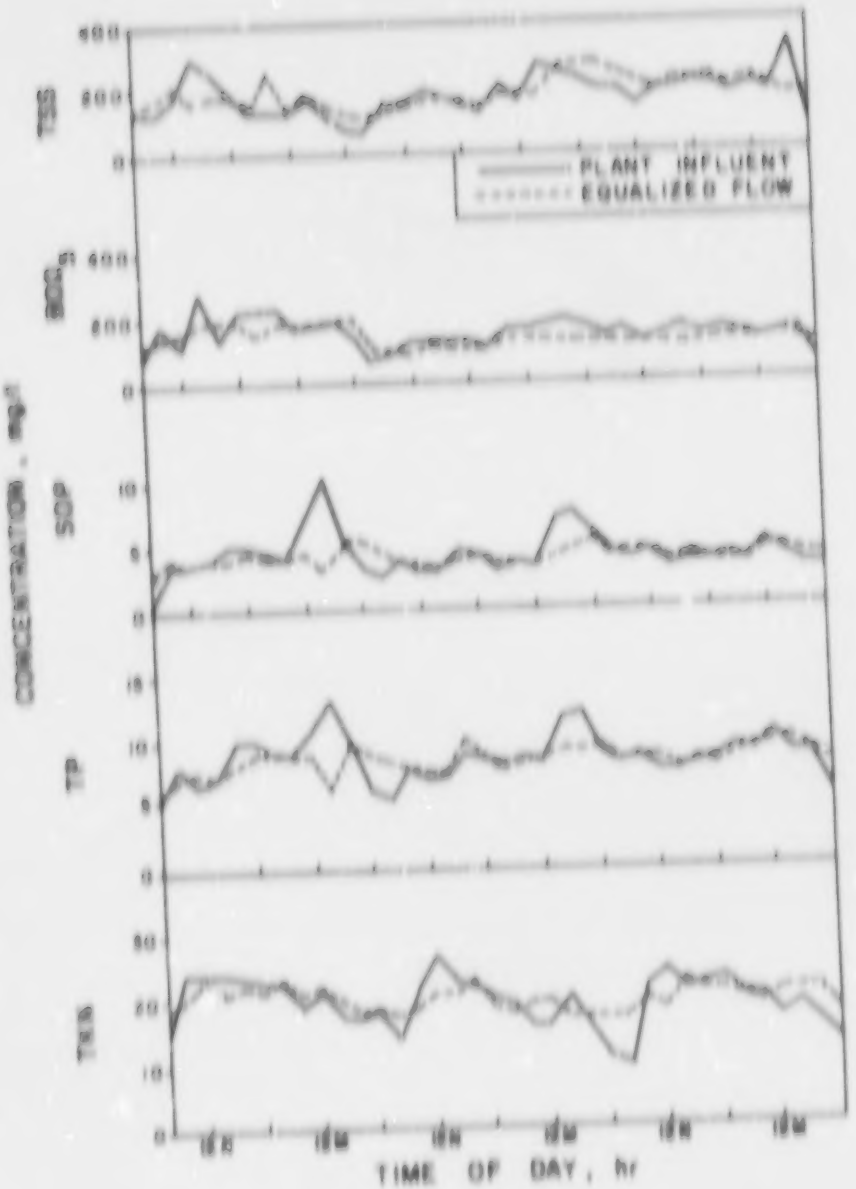

FIGURE 3 - Typical concentration variations in the influent and effluent of the equalization basin over a 72-hr period (April 14-16, 1975).

TABLE F

MASS BALANCE ACROSS EQUALIZATION BASIN

Period[1]	Statistical Property	Mass Flow Into Basin (lbs/8 hr)							Mass Flow Out of Basin (lbs/8 hr)						
		TSS	BOD$_5$	COD	TOC	TP	TKN	TVFA	TSS	BOD$_5$	COD	TOC	TP	TKN	TVFA
10/15 to 10/20/71 (6d values)	Mean	89,[illegible]	49,[illegible]	197,[illegible]	58.4	10.2	60.2	58.4	11,[illegible]	10,[illegible]	69,[illegible]	11.3	10.1	61.2	58.4
	Var./Mean	69,[illegible]	79,[illegible]	661,[illegible]	63.2	1.64	54.1	1.40	17,[illegible]	16,[illegible]	89,[illegible]	11.3	10.1	61.2	58.4
	Std. Dev.	182	243	811	8.0	1.28	8.1	1.18	1,[illegible]	1,[illegible]	1,[illegible]	1.8	1.8	8.1	8.1
	Coef. Var.	0.66	0.83	0.48	0.60	0.67	0.66	0.58	0.66	0.80	0.15	0.16	0.16	0.16	0.17
11/15 to 11/19 (6d values)	Mean	105,[illegible]	61,[illegible]	1,[illegible]	59.4	11.0	59.8	58.3	10,[illegible]	11,[illegible]	1,[illegible]	10.3	10.2	60.7	61.3
	Variance	151,[illegible]	60,[illegible]	660,[illegible]	7.10	1.66	2.19	1.64	1,[illegible]	1,[illegible]	1,[illegible]	1.23	1.3	3.3	3.3
	Std. Dev.	84	284	1,[illegible]	10.3	1.29	11.0	1.28	1,[illegible]	1,[illegible]	1,[illegible]	1.11	1.1	1.8	1.8
	Coef. Var.	0.71	0.58	0.58	0.61	0.60	0.61	0.60	0.58	0.66	0.11	0.66	0.10	0.10	0.11
12/15 to 12/19 (6d values)	Mean	110,[illegible]	60,[illegible]	265,[illegible]	16.1	12.5	59.0	17.3	10,[illegible]	1,[illegible]	1,[illegible]	10.3	10.0	60.3	10.4
	Variance	1,[illegible]	1,[illegible]	1,[illegible]	6.3	6.3	1.40	6.3	1,[illegible]	1,[illegible]	1,[illegible]	1.3	1.3	3.3	3.3
	Std. Dev.	1,[illegible]	1,[illegible]	1,[illegible]	2.0	2.5	11.8	2.5	1,[illegible]	1,[illegible]	1,[illegible]	1.1	1.1	1.8	1.8
	Coef. Var.	0.90	0.66	0.66	0.61	0.61	0.66	0.64	0.61	0.66	0.10	0.61	0.17	0.61	0.60
1/15 to 1/18/71 (6d values)	Mean	60,[illegible]	10,[illegible]	1,[illegible]	10.3	12.1	58.5	61.1	100,[illegible]	10,[illegible]	1,[illegible]	10.3	10.3	60.3	60.4
	Var./Mean	1,[illegible]	1,[illegible]	1,[illegible]	6.3	6.3	12.5	1.8	1,[illegible]	1,[illegible]	1,[illegible]	1.3	1.3	3.3	3.3
	Std. Dev.	1,[illegible]	1,[illegible]	1,[illegible]	2.0	2.5	11.8	2.5	1,[illegible]	1,[illegible]	1,[illegible]	1.1	1.1	1.8	1.8
	Coef. Var.	0.66	0.66	0.66	0.61	0.66	0.66	0.66	0.66	0.66	0.19	0.66	0.66	0.17	0.66
6/15 to 6/17 (6d values)	Mean	10,[illegible]	11,[illegible]	1,[illegible]	11.1	11.3	61.3	61.8	10,[illegible]	1,[illegible]	1,[illegible]	11.1	10.6	10.5	11.5
	Variance	1,[illegible]	1,[illegible]	1,[illegible]	6.3	6.3	6.3	6.3	1,[illegible]	1,[illegible]	1,[illegible]	1.3	1.3	1.3	1.3
	Std. Dev.	1,[illegible]	1,[illegible]	1,[illegible]	2.5	2.5	2.5	2.5	1,[illegible]	1,[illegible]	1,[illegible]	1.1	1.1	1.1	1.1
	Coef. Var.	0.11	0.11	0.11	0.66	0.66	0.19	0.66	0.11	0.66	0.19	0.16	0.11	0.15	0.17
All Periods Combined	Mean	696	666	1,[illegible]	10.1	11.1	60.6	11.6	110	111	1,[illegible]	10.1	10.0	11.1	10.1

[1] The intervals leaving out 6d of 1/11 to 1/18 and 6/10 to 7/1 are not included because the plant flow meter was out of service the periods 1/18 to 6/11, 6/1 to 6/5 and 6/10 to 6/11 are not included because the equalization basin was not in service

NOTE: lbs x 0.453 = kg

parameter across the equalization basin were generally in the range of 65 to 95 percent as compared to the 20 to 80 percent variance reduction in constituent concentrations across the equalization basin. Mass dampening is expected to be greater than concentration dampening because the former is a function of both flow and concentration equalization. Figure 4 illustrates mass leveling for a representative 72-hour period.

Mass Transformations Within the Equalization Basin

The mass flow data summarized from the hourly testing periods shown in Table 7 give insight into the changes that equalization produced in the waste as a result of biochemical reactions within the basin. A comparison of the mass flow into and out of the equalization basin, using the combined mean values in Table 7, shows that there were reductions in BOD_5, COD, SOP, and NH_3-N and increases in TSS and TON. Total phosphorus remained virtually constant across the basin, which is the expected result based on conservation of mass. These changes are consistant with those expected to occur as a result of biochemical action and associated growth of biomass in the equalization basin. However, it can be observed that overall BOD_5 removal for the combined periods was only 7 percent and was inconsistent from one study period to the next.

Additional mass flow data compiled and summarized from the daily plant records which extend from June, 1974 to July, 1975 are given in Table 8. These data are comparable to the hourly data in that they show a definite increase in suspended solids across the equalization basin but marginal and inconsistent BOD_5 removal. These results tend to confirm that growth of biomass occurred in the equalization basin but that there was little net removal of BOD_5. It should be mentioned, however, that these data have the limitation that composite samples were not proportioned according to flow (See Section VII).

To determine if the differences in monthly mean values of BOD_5 and TSS in the influent and effluent of the equalization basin are significant, the test statistic Z_0 was computed (See Table 8). Since it was hypothesized that there would be a BOD_5 reduction and a TSS increase across the basin, the one-sided test was used and the difference in means was considered significant at the 5% level of significance ($\alpha = 0.05$)

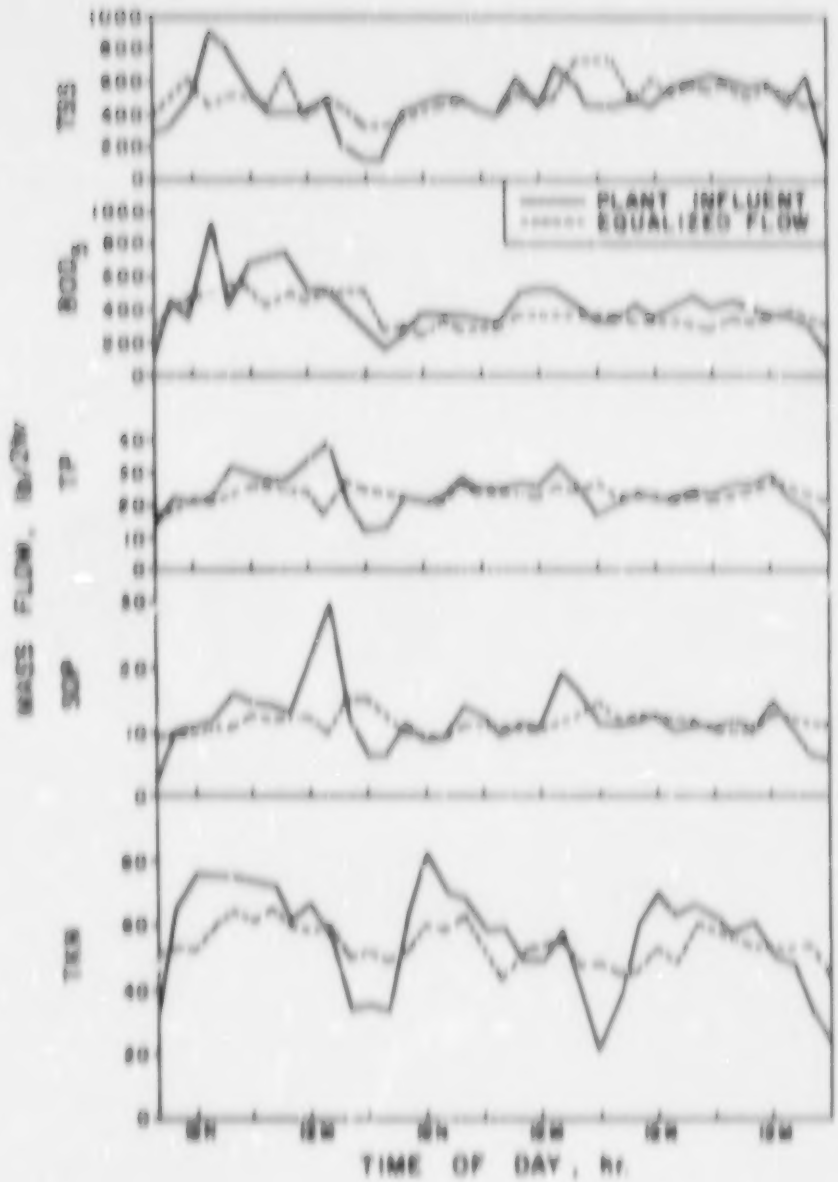

FIGURE 9 - Typical mass flow variations in the influent and effluent of the equalization basin over a 72-hr period (April 14-16, 1975).

TABLE 8

COMPARISON OF MEAN VALUES OF BOD_5 AND TSS IN RAW WASTE VERSUS EQUALIZATION BASIN EFFLUENT - DAILY DATA GROUPED BY MONTH

Period	BOD_5						TSS					
	Raw Waste		Equalization Basin Effluent		Percent Reduced in Basin	t_c [b]	Raw Waste		Equalization Basin Effluent		Percent Reduced in Basin	t_c [b]
	Mean [a]	Variance	Mean [a]	Variance			Mean [a]	Variance	Mean [a]	Variance		
June 1972	1,117	2,367,876	1,043	1,490,773	6.5	0.49	1,710	2,120,166	1,372	2,804,617	19.1	1.90
July	1,371	1,556,750	1,230	1,088,189	8.9	0.68	1,761	2,197,037	1,496	2,251,633	22.9	2.00
Aug.	1,295	1,181,888	1,077	1,669,630	9.2	0.86	1,692	1,847,880	1,470	2,671,796	13.1	2.13
Sept.	1,880	1,763,166	1,695	1,965,166	9.1	0.61	1,363	2,536,332	1,061	1,936,007	11.4	1.89
Oct.	1,763	1,728,751	1,733	1,670,077	2.2	0.03	1,886	1,570,236	1,622	1,633,184	0.2	1.84
Nov.	1,573	2,179,813	1,779	1,689,234	5.2	1.77	1,951	2,319,926	1,860	2,696,373	23.7	2.06
Dec.	1,716	1,518,213	1,573	2,666,531	20.6	1.51	1,888	2,281,881	1,586	2,860,272	18.1	1.50
Jan. 1973	1,995	2,218,951	1,788	1,290,301	3.7	1.81	2,219	2,723,162	2,133	2,038,636	11.9	2.10
Feb.	1,191	1,178,281	1,838	1,630,061	8.1	1.81	2,113	2,307,692	2,327	1,891,272	17.7	2.06
Mar.	1,912	2,791,693	1,698	2,183,607	12.8	0.31	2,397	2,696,339	2,782	1,178,767	21.9	2.17
April	1,681	1,614,986	1,719	1,800,653	5.1	0.31	2,966	2,163,301	2,523	2,713,616	16.7	2.43
May	1,995	630,377	1,812	1,817,851	2.9	0.12	2,972	301,360	2,221	1,230,302	3.5	1.29
June	2,130	2,362,370	2,256	1,191,823	--	0.35	2,378	2,120,849	2,161	1,616,760	--	0.48
July	2,151	2,281,073	2,151	2,281,073	--	0.00	2,776	861,268	2,908	864,872	--	0.32

[a] Units: Average of daily values. Note: All mean values are in (lb/day lb/day x 2.151 = kg/day).

[b] $t_c = \frac{\bar{y}_1 - \bar{y}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$ where $\bar{y}_1, \bar{y}_2$ are monthly means, s_1^2, s_2^2 are the monthly variances, and n is the number of days in the month.

if $Z_{calc} > 1.645$* for BOD_5 and $Z_{calc} < -1.645$ for TSS. From Table 8 it is seen from the Z_{calc} values that the mean values of BOD_5 across the equalization basin were significantly different in only one of the 14 months though 3 additional months were marginal. For TSS, there are several Z values close to the critical value which makes it difficult to reach a definite conclusion. Further statistical tests were run combining the data into 3-month groups to obtain the benefit of more observations per test. The results, presented in Table 9, show that the mean TSS value in the equalization basin effluent was significantly greater than the TSS value in the basin influent (at the 5% level of significance) for each of the periods tested. For BOD_5 there was only one period in which the difference across the basin was significant. These results further confirm that little or no BOD_5 reduction can be expected across an equalization basin but that some growth of biomass occurs, causing an increase in TSS.

Previously reported experience with preaeration of raw sewage has similarly shown that aeration (without sludge recycle) is relatively ineffective for BOD_5 removal. For example, Seidel and Baumann[19] found in full-scale studies that 48 minutes of preaeration had no measurable effect on the wastewater BOD_5. In-line equalization might be expected to provide somewhat higher levels of biological activity than a preaeration tank because of the longer mean liquid retention period.

Activated Sludge System

Operation and Performance --

Daily records of plant operation and performance were maintained by the treatment plant staff. A tabular summary of the conditions of operation for Plant No. 1 (the equalized plant) over a 19-month period is given in Table 10. Monthly average performance data for the plant during this same period are given in Tables 11 and 12. The equalization basin was in service throughout this period except for the 31 days from May 16, 1973 to June 16, 1973 when tests were performed under the unequalized mode.

*1.645 is the tabulated value of the test statistic Z for large n and $\alpha = 0.05$; see e.g. W. Mendenhall and R. L. Schaeffer, "Mathematical Statistics with Applications," Duxbury Press, North Scituate, Massachusetts, 1973, p. 332 ff.

TABLE 9

COMPARISON OF MEAN VALUES OF BOD_5 AND TSS IN RAW WASTE VERSUS EQUALIZATION BASIN EFFLUENT - DAILY DATA GROUPED IN 3-MONTH PERIODS

Period	BOD_5					TSS				
	Raw Waste		Equalization Basin Effluent			Raw Waste		Equalization Basin Effluent		
	Mean[a]	Variance	Mean[a]	Variance	t_c	Mean[a]	Variance	Mean[a]	Variance	t_c
June - Aug. 8 August (1971	3,161	1,990,033	3,183	1,603,761	0.09	3,253	2,348,601	4,036	3,695,969	-1.16
Sept. (Oct. 8 Oct. (1971	4,167	2,265,839	4,328	1,861,863	0.68	3,963	2,321,936	4,584	2,574,432	-1.18
Nov. (Dec. Feb (1971-72	4,166	3,383,371	3,843	2,109,383	1.46	4,858	3,071,200	3,633	2,781,027	2.11
Mar. - Apr. 8 May (1972	3,871	1,813,134	3,733	1,341,762	0.48	3,769	1,786	1,353	1,918,886	2.14

[a]All mean values are in (lbs/day) lbs/day x 0.454 = kg/day.

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TABLE 10

CONDITIONS OF OPERATION OF PLANT NO. 1 DURING STUDY PERIOD[a]

(Monthly Average of Daily Values)

Parameter	Units of Measure	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

TABLE II

PERFORMANCE OF PLANT NO. 1
DURING STUDY PERIOD - BOD_5 AND TSS

(Monthly Average of Daily Values)

Parameter	Statistical Property	June 1976	July	Aug	Sept	Oct	Nov	Dec	Jan 1977	Feb	Mar	Apr	May	June	July
BOD_5 in Raw Wastewater, mg/l	Mean	173	185	199	188	190	203	222	182	175	197	189	178	150	151
	Variance	1,481	1,822	2,414	1,809	2,167	1,724	4,661	1,461	1,824	2,225	1,661	1,515	1,825	2,100
	Std Dev	38	43	49	43	47	42	68	38	43	47	41	39	43	46
	Coef Var	0.22	0.23	0.25	0.23	0.25	0.21	0.31	0.21	0.25	0.24	0.22	0.22	0.29	0.30
BOD_5 in Secondary Effluent, mg/l	Mean	173	180	200	201	210	225	179	173	168	188	181	178	158	151
	Variance	661	784	1,722	1,661	1,741	1,964	1,111	1,083	1,831	1,104	1,386	1,521	1,115	1,100
	Std Dev	26	28	42	41	42	44	33	33	43	34	37	39	33	33
	Coef Var	0.15	0.16	0.21	0.21	0.20	0.20	0.18	0.19	0.25	0.18	0.20	0.22	0.21	0.22
BOD_5 in Final Effluent, mg/l	Mean	22	19	17	15	19	17	18	11	11	13	15	11	11	11
	Variance	64	49	105	25	32	16	25	3	4	8	12	4	4	3
	Std Dev	8	7	10	5	6	4	5	2	2	3	3	2	2	2
	Coef Var	0.36	0.36	0.57	0.34	0.31	0.24	0.28	0.18	0.17	0.23	0.20	0.18	0.17	0.18
BOD_5 Removed by Secondary Treatment	Mean	87.5	89.0	90.0	91.0	91.0	91.0	92.0	93.0	93.0	90.0	90.0	93.0	93.0	93.0
	Variance	16	12	23	12	11	11	14	11	14	13	12	11	11	11
	Std Dev	3.9	3.7	4.9	3.5	3.4	3.4	3.8	3.4	3.8	3.6	3.5	3.4	3.4	3.4
	Coef Var	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
TSS in Raw Wastewater, mg/l	Mean	175	183	187	187	201	199	221	181	175	195	191	185	165	174
	Variance	1,825	1,931	2,156	1,721	2,500	1,721	4,225	1,625	1,961	2,025	1,764	1,625	1,625	1,764
	Std Dev	43	44	46	41	50	41	65	40	44	45	42	40	40	42
	Coef Var	0.25	0.24	0.24	0.22	0.25	0.21	0.29	0.22	0.25	0.23	0.22	0.22	0.24	0.24
TSS in Secondary Effluent, mg/l	Mean	203	189	199	204	220	199	201	197	174	191	191	190	163	163
	Variance	2,116	1,936	2,704	2,164	2,025	1,681	2,809	2,209	1,764	2,401	2,116	1,681	1,936	1,936
	Std Dev	46	44	52	46	45	41	53	47	42	49	46	41	44	44
	Coef Var	0.23	0.23	0.26	0.23	0.20	0.21	0.26	0.24	0.24	0.26	0.24	0.22	0.27	0.27
TSS in Final Effluent, mg/l	Mean	18	16	20	15	19	22	11	12	13	15	15	8	11	9
	Variance	169	64	441	9	25	400	49	196	169	225	196	64	81	49
	Std Dev	13	8	21	3	5	20	7	14	13	15	14	8	9	7
	Coef Var	0.72	0.49	1.05	0.20	0.26	0.91	0.63	1.17	1.00	1.00	0.93	1.00	0.82	0.78
% TSS Removed by Secondary Treatment	Mean	88.7	91.0	89.3	91.0	91.0	89.0	91.0	93.0	92.0	92.0	92.0	95.0	93.3	94.3
	Variance	30.1	12	56	12	12	56	12	12	12	12	12	6.0	6.0	6.0
	Std Dev	5.5	3.5	7.5	3.5	3.5	7.5	3.5	3.5	3.5	3.5	3.5	2.5	2.5	2.5
	Coef Var	0.06	0.04	0.11	0.04	0.04	0.11	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03

TABLE 12

PERFORMANCE OF PLANT NO. 1
DURING STUDY PERIOD - VSS AND TP

(Monthly Average of Daily Values)

Parameter	Statistical Property	June 1974	July	Aug	Sept	Oct	Nov	Dec	Jan 1975	Feb	Mar	Apr	May	June	July
VSS in Raw Wastewater, mg/l	Mean	135	120	105	107	147	135	143	113	109	83	93	110	104	112
	Variance	4706	1355	2400	4601	6116	6400	5005	6825	6401	3965	1156	604	1067	676
	Std Dev	69	36	49	51	66	80	71	83	80	63	34	33	33	26
	Coef Var	0.51	0.30	0.46	0.46	0.45	0.59	0.49	0.74	0.73	0.76	0.37	0.30	0.32	0.23
VSS in Secondary Basin Effluent, mg/l	Mean	151	131	110	151	113	133	143	161	109	95	119	120	104	112
	Variance	8401	1403	1935	1225	1056	6399	4706	6956	6401	676	1401	1005	1400	676
	Std Dev	92	37	44	35	32	80	69	83	80	26	37	32	37	26
	Coef Var	0.70	0.28	0.39	0.23	0.27	0.59	0.48	0.74	0.73	0.27	0.31	0.26	0.36	0.23
VSS in Final Effluent, mg/l	Mean	17	19.3	20	11	16	10	9.0	11.8	17	4.7	8.3	9.5	11	5
	Variance	121	45	675	41	49	161	13	25	401	16	196	13	196	16
	Std Dev	11	7	26	6.4	7	13	3.6	5.0	20	4	14	3.6	14	4
	Coef Var	0.65	0.40	1.3	0.57	0.44	1.3	0.41	0.42	0.59	0.98	1.7	0.65	1.3	0.80
% VSS Removed by Secondary Treatment	Mean	71.4	83.3	85.3	83.4	88.5	83.1	83.1	88.8	83.2	94.0	87.4	89.4	91.7	89.4
	Variance	60.3	20.5	84	16.3	19.2	7.52	17.1	20.6	74	11.7	87.3	269	1.92	7.25
	Std Dev	7.77	4.53	9.1	3.78	4.38	2.74	4.14	4.55	8.6	3.4	9.34	16.4	1.39	2.69
	Coef Var	0.07	0.05	0.10	0.04	0.05	0.14	0.04	0.07	0.11	0.11	0.07	0.18	0.15	0.03
TP in Raw Wastewater, mg/l	Mean	11.4	8.9	8.9	8.2	9.3	8.2	8.5	7.3			7.3		8.4	7.3
	Variance	1.65	2.0	1.6	0.70	1.0	1.0	1.3	1.5			0.43		1.3	0.68
	Std Dev	14.9	1.4	1.3	0.84	1.0	1.0	1.1	1.2			0.65		1.1	0.82
	Coef Var	1.3	0.16	0.14	0.10	0.10	0.11	0.12	0.16			0.09		0.13	0.11
TP in Final Effluent, mg/l	Mean	1.8	2.1	2.0	1.3	2.3	2.5	1.2	2.2	1.7	1.0	1.3	2.0	1.2	0.99
	Variance	0.4	1.13	0.85	0.19	0.68	1.3	0.18	1.5	1.3	0.10	0.48	1.8	16	0.27
	Std Dev	0.6	1.1	0.92	0.44	0.82	1.1	0.42	1.2	1.1	0.32	0.69	1.3	4	0.52
	Coef Var	0.33	0.53	0.46	0.34	0.37	0.43	0.33	0.53	0.65	0.34	0.51	0.63	3.3	0.51
% TP Removed by Secondary Treatment	Mean	71.5	76.8	77.9	84.3	73.3	70.6	84.8	70.3	79.8	78.1	81.5	78.6	85.6	86.5
	Variance	61.8	265	69.4	31.5	166	161	34.3	346	213	84.3	83.1	214	1163	35.3
	Std Dev	7.11	17.3	8.91	5.65	14.3	13.9	6.08	19.8	14.8	9.69	9.19	15.5	34.8	5.96
	Coef Var	0.10	0.23	0.12	0.07	0.20	0.17	0.07	0.31	0.19	0.07	0.11	0.23	0.41	0.07

As shown in Table 10, raw wastewater flow rates were similar throughout the 15-month period, averaging 13,970 m^3/day (3.69 mgd). The final clarifiers operated with an average overflow rate of 32.8 $m^3/day/m^2$ (803 gpd/sq ft) which slightly exceeds the design value of 32.6 $m^3/day/m^2$ (800 gpd/sq ft). Recycle sludge flow rates averaged 69 percent of the influent flow rate during this period. Mixed-liquor D.O. concentrations were maintained at an average of 2.1 mg/l (for measurements taken at the head of the aeration basin). The mean aeration period was 6.1 hr and the mean aeration rate was 119,980 m^3/day (4,236,300 cu ft/day) which is equivalent to approximately 0.0086 m^3/l (1.15 cu ft/gal) of sewage treated.

Table 10 also shows that there was some difficulty in maintaining a constant MLSS concentration throughout the study period. The mean MLSS concentration during the 15-month period was 1977 mg/l, with monthly mean values ranging from 1661 mg/l to 2733 mg/l. The organic loading intensity, F/M, also varied considerably, exhibiting a range of 0.39 to 0.80 g/g day (lb/lb day) and a mean of 0.55 g/g day (lb/lb day).

To illustrate the treatment effectiveness of Plant No. 1, values of some wastewater quality parameters for the plant influent, equalization basin effluent, and final effluent are given in Tables 11 and 12. Also shown are the percentage of BOD_5, TSS, VSS and TP removed by secondary treatment. As in most of the data presented here, values for the mean, standard deviation, variance, and coefficient of variation are listed in each instance.

As illustrated by examination of the data in Tables 11 and 12, the percentage removals of BOD_5, TSS and VSS were relatively consistent throughout the study period and were typical of those expected from a conventional activated sludge plant (averaging about 91 percent for all three parameters). Percentage removals of TP across the plant were not consistent, ranging from 39 to 87 percent, and reflect some of the difficulties with the ferric chloride feed system (pump malfunctions and line plugging). These difficulties did not appear to have much effect on TSS removal in the plant.

Figure 5 illustrates TSS and BOD plant effluent data collected under unequalized and equalized flow during March-July 1975. There is little apparent difference evident in the level or consistency of effluent TSS and BOD concentrations obtained under each condition. Effluent TSS concentrations averaged 9 mg/l during the unequalized flow

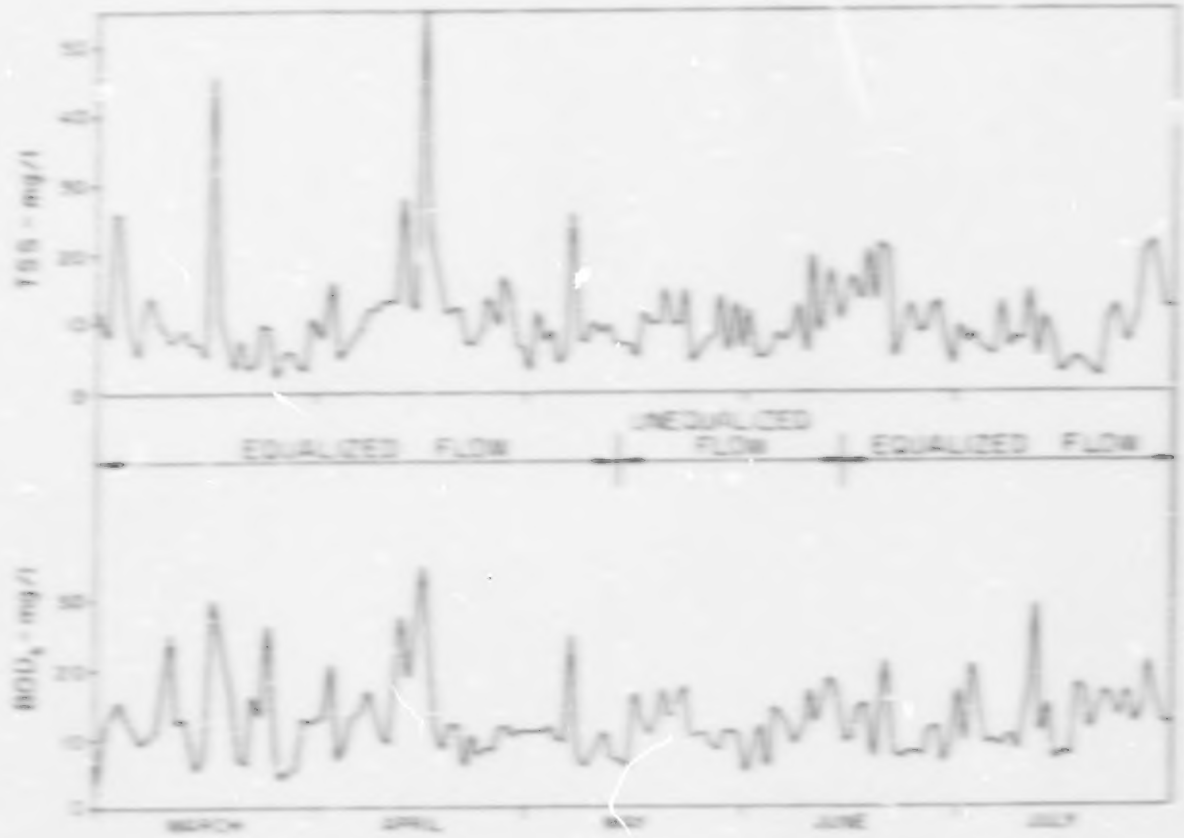

FIGURE 1– Concentration of BOD_5 and suspended solids in plant No. 1 effluent during periods of equalized and unequalized flow. (1973).

TABLE 13

CONDITIONS OF OPERATION AND PERFORMANCE OF PLANT NO. 1 DURING PERIODS OF EQUALIZED AND UNEQUALIZED FLOW[a]

Item	11-Day Equalized Flow Period[b]			11-Day Unequalized Flow Period[c]			11-Day Equalized Flow Period[b]		
	Mean	Range in Data	Coefficient of Variation	Mean	Range in Data	Coefficient of Variation	Mean	Range in Data	Coefficient of Variation
Influent to Aeration Basin									
Flow Rate, m^3/day									
Temperature, °C									
BOD, mg/l									
COD, mg/l									
TOC, mg/l									
Suspended Solids, mg/l									
Volatile Suspended Solids, mg/l									
Fixed Suspended Solids, mg/l									
Primary Effluent									
BOD, mg/l									
COD, mg/l									
TOC, mg/l									
Aeration Basin									
BOD Removed, mg/l									
COD Removed, mg/l									
TOC Removed, mg/l									
Organic Load, kg BOD per m^3/day									
Detention Time, hours									
Food-Supplied Oxygen Rate, kg/hr									

[a] Note: mgd x 3785 = m^3/day; °F - 32 x 0.555 = °C; ft/sec x 0.305 = m/sec

[b] [illegible]

[c] [illegible]

[d] See table of for definition

period versus 14 mg/l and 11 mg/l during the two equalized flow periods, while effluent BOD_5 concentrations averaged 11 mg/l during the unequalized flow period versus 12 mg/l and 13 mg/l during the two equalized flow periods. Table 13 presents a summary of the average conditions of operation and mean performance values for the 31-day period of unequalized operation and for the two 31-day periods of equalized flow which preceded and followed unequalized operation. Like Figure 5, Table 13 shows that final effluent quality (in terms of BOD, TSS and VSS) and percentage removals were very similar during the respective 31-day periods of comparison. Throughout the periods of testing, the plant operated without upset and, as shown in Table 13, exhibited good sludge settleability. While unavoidable changes occurred in some of the operating parameters, such as F/M, the principal experimental variable was the presence or absence of diurnal flow variations; thus, in this practical situation, flow equalization had little or no beneficial effect on plant effluent quality.

Intensive Studies

The limited amount of bihourly data which was collected on the final effluent stream of the equalized plant is included in Tables 5-6. The conditions of operation during the periods for which bihourly effluent data were collected are summarized in Table 14. Some helpful insight into the effects of equalization can be gained by examining these study periods individually.

During the intensive study periods in March through June, 1973, the emphasis in the experimental program was on (i) stressing Plant No. 1 in the equalized mode by selectively removing final clarifiers from service, thereby increasing the overflow rate in the final clarifiers, and (ii) taking the equalization basin out of service and running Plant No. 1 under stressed and unstressed conditions with normal diurnal flow variations. These experiments were undertaken to permit comparison of plant performance under both equalized and unequalized flow conditions and at both normal and elevated final clarifier overflow rates.

(i) On March 10, four clarifiers were removed from service at 8:30 a.m. The effluent deteriorated with high suspended solids carryover; measurements taken every half-hour showed that TSS reached 300 mg/l and BOD_5 was as high as 178 mg/l. During this period, the plant flow was equalized at 15,900 m^3/day (4.2 mgd), which

TABLE 19

CONDITIONS OF OPERATION OF PLANT NO. 1 DURING PERIODS OF BIHOURLY TESTING [a,d]

(Average of Daily Values Over Period)

Parameter	8/17 to 8/18 1973[c]	8/15 to 8/17 1973[c]	8/18 to 8/20 1973[c]	8/1 to 8/3 1973[c]	8/13 to 8/15 1973[c]	8/30 to 9/1 1973[c]
Wastewater Flow, mgd	5.30	5.16	5.09	5.16	5.15	5.57
Aeration Period, hr	5.5	5.5	5.2	6.7	6.5	6.5
MLSS, mg/l	1,366	2,661	1,536	1,597	1,196	2,178
MLVSS, mg/l	996	1,866	1,176	969	882	1,384
Mixed Liquor D.O., mg/l	1.01	1.55	1.78	1.55	2.17	5.85
Settleability[f]	0.13	0.15	0.12	0.12	0.09	0.23
Applied Air, 1,000 cu ft/day	5,971	5,853	5,649	5,314	5,593	5,866
Sludge Recycle Ratio, %	60	59	61	71	71	61
F/M, lb/lb day	0.96	0.43	0.66	0.71	0.77	0.51
Clar. Overflow Rate, gpd/sq ft	515:1151[b]	592:1360[b]	587	969[b]	1356[b]	1002[b]
Clar. Solids Load, lbs/day/sq ft	21.5:27.0[b]	21.4:15.1[b]	15.8[b]	16.9[b]	18.1[b]	29.1[b]

[a]Only those periods for which hourly plant effluent data were obtained are shown.
[b]Note: mgd x 3.785 = m³/min; cu ft/day x 0.028 = m³/day; gpd/sq ft x 0.0408 = m³/day/m²; lb/day/sq ft x 4.88 = kg/day/m²
[c]Plant flow was equalized.
[d]Aeration basin was out of service; normal diurnal flow conditions prevailed.
[e]Clarifier overflow and solids loading rates were increased during part or all of these periods by intentional removal of some units from service; see text for description.
[f]See Table 18 for definition.

gave a final clarifier overflow rate of 74.7 $m^3/day/m^2$ (1830 gpd/sq ft) based on a surface settling area of 213 m^2 (2,296 sq ft). The solids loading was about 129 $kg/day/m^2$ (26.5 lbs/day/sq ft). All clarifiers were put back on line at 10 a.m. after 1-1/2 hours because of continued poor effluent quality.

(2) On March 17, three large clarifiers were removed from service at 9:00 a.m. yielding an available surface settling area of 228 m^2 (2450 sq ft). Plant flow rate at the time was equalized at about 16,273 m^3/day (4.3 mgd) which gave an overflow rate of 71.6 $m^3/day/m^2$ (1755 gpd/sq ft) and a solids loading of about 132 $kg/day/m^2$ (27 lbs/day/sq ft). Results were poor, necessitating that the experiment be suspended. Beginning at 11:00 on the same day, the plant was operated after taking two small clarifiers and one large clarifier off-line. The resulting arrangement produced a surface settling area of 280 m^2 (3,010 sq ft) and an overflow rate of about 58.1 $m^3/day/m^2$ (1430 gpd/sq ft). Based on MLSS of 1266 mg/l and a recycle rate of 60%, the solids loading was 118 $kg/day/m^2$ (24.1 lbs/day/sq ft). A good effluent was produced with BOD_5 and TSS values averaging less than 10 mg/l; however, the experiment was terminated at 3:00 p.m. after 4 hours of operation by instructions from the plant operator.

(3) On April 14, four small clarifiers were taken out of service at 9:00 a.m. leaving 264 m^2 (2842 sq ft) of surface settling area remaining (with equalized flow). The effluent deteriorated rapidly, necessitating that the clarifiers be put back on line within one hour. Part of the problem with this particular mode of operation seemed to be an uneven flow distribution among the clarifiers.

(4) On April 16, three small clarifiers were removed from service at 9:00 a.m. under equalized flow conditions. The resulting surface settling area of 306 m^2 (3290 sq ft) and plant flow rate of 16,650 m^3/day (4.4 mgd) produced an average overflow rate of 55 $m^3/day/m^2$ (1340 gpd/sq ft). The solids loading was approximately 17 $kg/day/m^2$ (35.1 lbs/day/sq ft), based on MLSS of 2268 mg/l and a recirculation ratio of 38%. Effluent quality was generally poor with progressive deterioration through the day; BOD_5 results were better than those for TSS but hexavalent chromium and phenols were detected in the wastewater and it is possible that the BOD_5 results were low due to toxic effects.

(5) During the May 18-22, June 3-5, and June 10-12 study periods, the equalization basin was removed from service. The performance and operation data (Tables 3-6 and Table 14) show that final effluent quality was good during each period, despite the fact that the plant was stressed during the latter two periods by removing final clarifiers from service. These results indicate that the plant is capable of producing a good effluent with or without flow equalization.

(6) From June 30 to July 2, 1975, the plant was operated in the equalized mode but two clarifiers were taken off-line to obtain performance data under stressed conditions. The average plant flow for the three days of testing was 13,130 m^3/day (3.47 mgd), yielding an average final clarifier overflow rate of 41 m^3/day/m^2 (1002 gpd/sq ft) based on a surface settling area of 322 m^2 (3,462 sq ft). The MLSS concentration was 2,178 mg/l and the sludge recycle rate 64%, resulting in a clarifier solids loading of 143 kg/day/m^2 (29.7 lbs/day/sq ft). The performance data indicate that there was no apparent effluent quality deterioration during the testing period.

(7) On July 28, four clarifiers, representing half of the plant's clarifier capacity, were removed from service at 9:00 a.m. During the testing period, the final clarifier overflow rate averaged 39 m^3/day/m^2 (1440 gpd/sq ft) based on a surface settling area of 213 m^2 (2,296 sq ft). The solids loading exceeded 171 kg/day/m^2 (35 lbs/day/sq ft) based on MLSS of 1,832 mg/l and a recirculation ratio of 62%. Effluent quality remained stable but then began to progressively deteriorate after about 12 hours; TSS measurements on hihourly samples reached 78 mg/l after 28 hours. A similar experiment was conducted on August 5 with virtually identical results. These findings showed that there can be a considerable lag period (10-12 hs) before the effects of a substantial increase in final clarifier overflow rate are observed in the final effluent. However, as described above, previous testing (particularly that conducted on March 16 in which the same clarifiers were taken out of service under similar conditions) generally showed much shorter lag periods before the effluent quality deteriorated. The difference is attributable to (a) more efficient solids return in the later testing (because the clarifiers and sludge return lines had been cleaned of blockages and deposits in the interim), and (b) lower initial sludge levels in the clarifiers for the later testing periods.

The final effluent data in Tables 3-6 along with the preceding discussion suggests that the effects of flow equalization on the performance of this activated sludge system were less important than the effects of other operational variables. First, plant performance was similar under both equalized and unequalized conditions, even when the final clarifiers were stressed. If anything, the performance of the plant, as measured by the mean and variance of the hiheurly effluent TSS and BOD data, was marginally better when the flow was unequalized (See Table 1 and the corresponding conditions of operation in Table 19). Second, there was continuing difficulty throughout these studies in maintaining control over the operating conditions and this lack of rigid control undoubtedly affected the effluent quality, irrespective of equalization. For instance, there were problems in operating the Ypsilanti plant with a constant BOD loading intensity. Likewise, there are various other factors which may affect effluent quality, including sludge settleability, wind and density currents, recycle rate, sludge blanket height, chemical dose (for P precipitation), etc. Not all of these variables could be controlled at the plant nor would they be likely to be rigidly controlled at most manually-operated plants. Therefore, without proper operational control, this study indicated that benefits of flow equalization, if any, can be lost.

Another factor which would tend to minimize performance differences between equalized and unequalized plants is the insensitivity with which final clarifiers appear to respond to changes in flow rate, even at high hydraulic loadings. Figure 6 shows that there was a time lag on the order of 12 hours before the effect of a substantial increase in clarifier loading was observed in the effluent during one representative experiment at the plant (See Item (7) above). Response times of this magnitude would act to diminish any adverse impact of normal diurnal flow variations at a plant. Similar results were observed in other runs, although as previously discussed the time lag was not always as long as 12 hours before the effluent deteriorated. Based on our observations, variable flows have limited impact on final clarification efficiency except where the solids loading becomes limiting, causing a build-up in the clarifier sludge inventory, raising of the sludge blanket, and eventual carryover of solids.

A further indication that final clarifier performance is relatively insensitive to flow variations is illustrated in Figure 7. Here, TSS concentrations in grab samples of secondary effluent are plotted as a function of overflow rate at the time of sampling, for samples collected under diurnal flow conditions. It is evident that the two variables

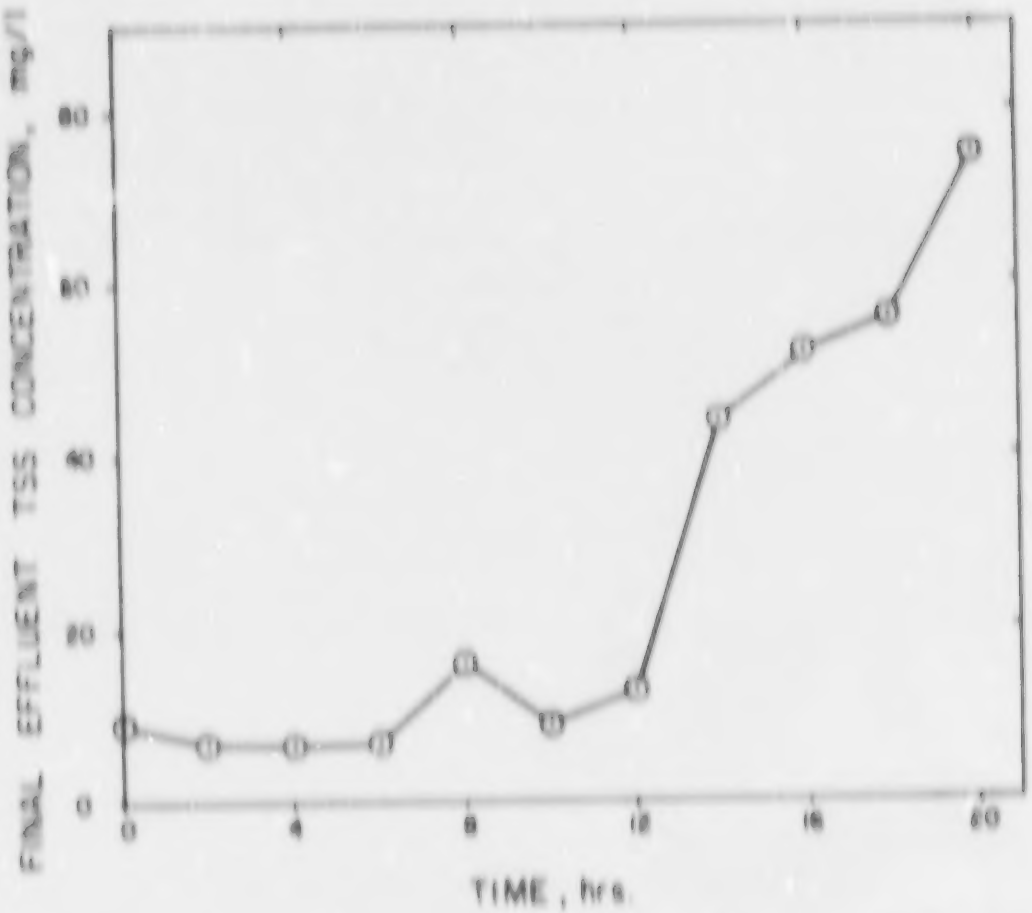

FIGURE 6 Response of secondary clarifier effluent suspended solids concentration to an increase in loading (overflow rate increased at time zero from 720 to 1440 gpd/sq ft (29.4 to 58.8 m^3/day/m^2); corresponding solids loading increased from 18 to 35 lbs/sq ft/day (87.8 to 171 kg/day/m^2).

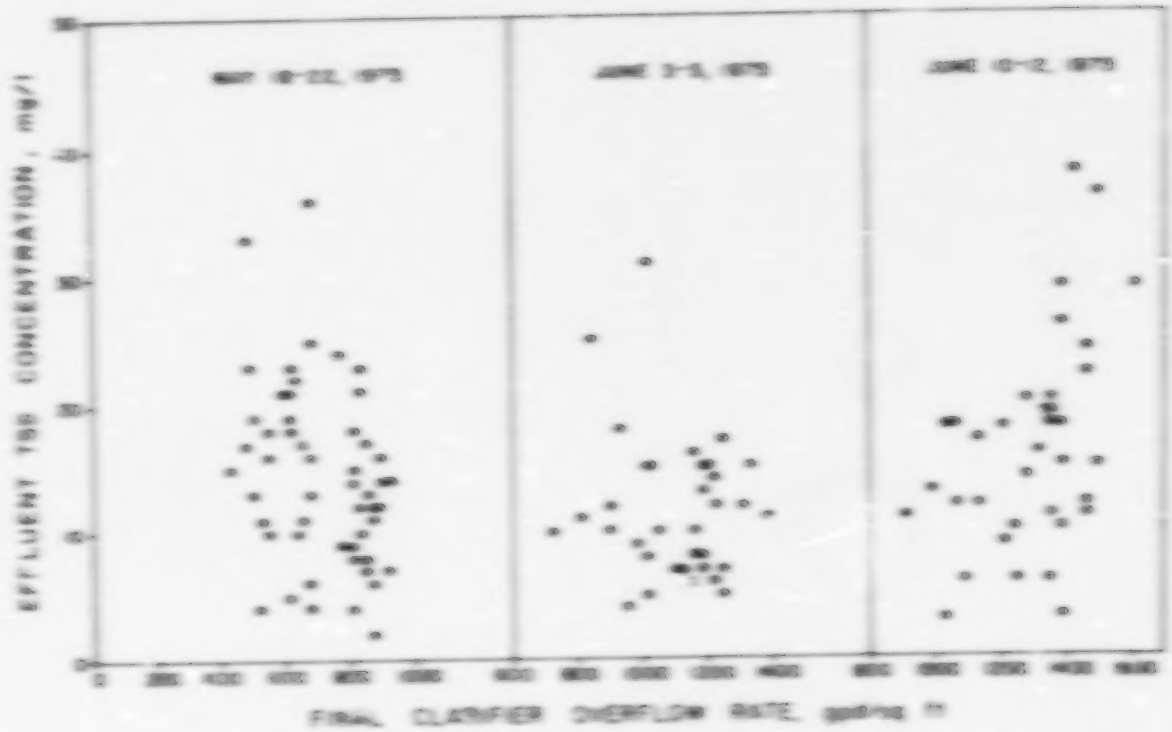

FIGURE 7 - Concentration of suspended solids in 24-hourly samples of final effluent versus final clarifier overflow rate at the time of sampling - diurnal flow conditions.

do not correlate very well, although there is some indication that the effluent TSS deteriorated with overflow rates above 37 $m^3/day/m^2$ (1400 gpd/sq ft). These data were subjected to linear and nonlinear regression analysis to determine if there was a definite linear or log-log linear relationship between the effluent TSS concentration and the instantaneous flow rate occurring at the time of sampling. Additional analyses were also run for lag periods on flows of 1 hour and 2 hours to determine if effluent TSS concentration was more strongly related to the flows 1 or 2 hours earlier. All regression analyses indicated a lack of significance at the 5 percent level between effluent TSS and flow.

Special Studies

Effects of Equalization on Wastewater Temperature

Temperature readings were taken on the influent and effluent of the equalization basins over a period of several months at times when the basins were full or nearly full, i.e., when the retention time was greatest. Based on 131 daily measurements between June, 1974 and February, 1975, it was found that the equalization basin resulted in temperature changes of the influent wastewater of less than 1°C. Influent wastewater temperature varied from a monthly average of 20°C in August, 1974, to 11°C in January, 1975. Sometimes the apparent effect of equalization was to increase the temperature of the wastewater and sometimes to decrease it. Since the thermometer used to take the measurements was only read to the nearest 0.5°C, we believe the differences are largely explainable in terms of the low precision of measurement. The conclusion reached is that the closed equalization basins at Ypsilanti Township had no significant effect on wastewater temperature.

Aeration Requirements for Equalization

A brief study was performed to determine the minimum air flow rate necessary to both maintain aerobic conditions and prevent sedimentation of solids in the equalization basin. To facilitate the work and make it more generally applicable, only one of the two equalization basins was used; the second tank was taken out of service by closing all valves to the tank. Compressed air was fed to the first tank at rates of 4.2, 8.4, 13.0 and 16.8 m^3/ min (150, 300, 460 and 600 cfm). After adjusting the air flow rate to the

desired value, the D.O. concentration was allowed to equilibrate at levels indicated in Figure 8. Dissolved oxygen and TSS measurements were obtained at depths of 0.3, 3.6 and 6.6 m (1, 11 and 21 ft) below the water surface representing the top, midpoint, and bottom of the tank. The tank was at full liquid depth (See Figure 2) and contained 1181 m^3 (312,000 gal) of water at the time of the measurement which corresponded to a theoretical detention time of about 4.2 hr. The samples and measurements were taken through a manhole in the cover of the equalization basin about half way between the center and periphery of the basin.

Results of the study are presented graphically in Figure 8. It was observed that sedimentation of solids apparently occurred only at the lowest level of aeration (3.7×10^{-6} $m^3/min/l$, 0.3 cfm/1000 gal). Aerobic conditions prevailed throughout the basin even at the lowest level of aeration, although the D.O. content decreased with distance from the air nozzles, achieving a minimum of 2.3 mg/l at a depth of 0.3 m (1 ft) below the surface at an air flow of 4.2 m^3/min (150 cfm). These results indicate that the aeration requirements for providing complete mixing are greater than for maintaining aerobic conditions in an equalization basin. The minimum level of aeration for preventing solids deposition was about 7.5×10^{-6} $m^3/min/l$ (1.0 cfm/1000 gal) of storage.

Operational Problems During Study

The following operational problems were experienced in the equalized plant (Plant No. 1) during the course of the study:

1. Rags and Debris -- In the initial phase of the study, Plant No. 1 had no pretreatment facilities. Therefore, rags and other debris tended to accumulate in the aeration compartments and, eventually, the final settlers. These rags caused problems in the operation of the return sludge system by plugging the sludge return lines. This was remedied by installing a manually cleaned bar rack in the influent channel.

2. Influent Metering -- There were a few occasions on which the influent magnetic flow meter was inoperative.

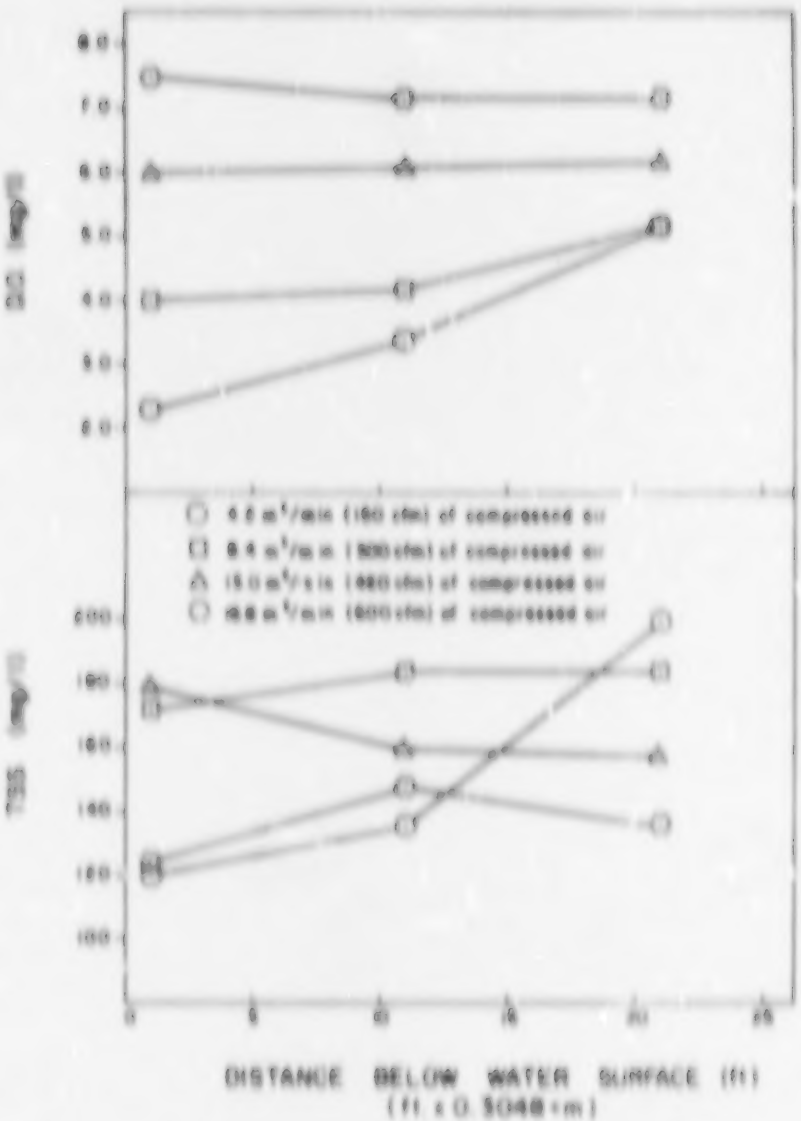

FIGURE 8 - Depth profiles of TSS and D.O. in the equalization basin at different levels of air input. (Note: Basin liquid volume = 1181 m^3 (312,000 gal); water temperature = 19°C.)

4. Maintenance of Constant MLSS -- There was difficulty experienced in maintaining a stable MLSS concentration at both plants. This problem was at least partially caused by the interconnected sludge piping systems of the two plants which severely limited operational control over sludge wasting.

5. Sampling -- Special sampling lines were installed so that most samples could be taken at a sink inside the control building. Nevertheless, some problems with plugged lines were encountered, and it was decided to collect all samples directly at the sample point.

6. Ferric Chloride and Polymer Feed Systems -- The ferric chloride and polymer feed lines were subject to occasional plugging or freezing. Such problems were usually corrected within a day.

7. Manpower Requirements -- There was insufficient manpower on the Ypsilanti Township staff to rapidly respond to some of the non-routine duties and requirements inherent in plant-scale research. The function of the project research personnel was mainly sampling and analysis, and they were limited in their ability to carry out or assist in any aspects involving plant operations. Conversely, treatment plant personnel were not able to assist in performing some of the additional sampling and analysis that might have been desirable.

Cost Considerations

The actual construction cost for upgrading Plant No. 1 and providing flow equalization is itemized in Table 15 according to the contractor's breakdown. The work consisted principally of a) piping additions and deletions to convert existing primary clarifiers to secondary clarifiers; b) grit chamber modifications; c) installation of a completely new diffused air system for the aeration basins; and d) installation of equipment and appurtenances necessary for converting existing digesters to equalization basins, including an equalization pump, piping, control valving, compressed air system, and instrumentation.

Costs associated with the equalization system were not itemized separately by the construction contractor but have been estimated as shown in Table 16. The estimated

TABLE 13

CONSTRUCTION COST
YPSILANTI TOWNSHIP PLANT NO. 1 IMPROVEMENTS[a]

Item	Cost
General Conditions	$ 20,000
Bond	3,500
Piping	102,300
Pumps	19,000
Air Compressors	39,000
Air Diffusers	13,000
Barminutor	11,000
Sheet Metal	1,000
Instrumentation	42,000
Architectural Work	42,000
Insulation	2,000
Electrical	38,489
Miscellaneous Change Orders	36,913
TOTAL	$390,200

[a]Costs shown are the actual construction costs itemized according to the contractor's schedule; the date of the construction contract was May 31, 1972 (EPA Sewage Treatment Plant Cost Index 183); construction was completed in August, 1973.

TABLE 16

CONSTRUCTION COST
YPSILANTI TOWNSHIP PLANT NO. 1 EQUALIZATION SYSTEM[a]

Item	Cost
Equalization Pump and Controls	$ 10,800
Piping and Valves	39,700
Air Compressors and Piping	20,000
Electrical and Controls	18,300
TOTAL	$ 85,000

[a]Engineers estimate (EPA Cost Index 183).

cost for the equalization facilities of $85,000 is only about 25% of the cost for equalization that would have been experienced had new concrete equalization basins been constructed.

Use of flow equalization at the plant was necessary to gain state approval for the conversion of the primary clarifiers to secondary clarifiers. Thus, provision of flow equalization was cost effective in this case because, in effect, it eliminated the need for costly construction of new secondary clarifiers. In general however, flow equalization would not be considered a substitute for primary sedimentation.

Operation and maintenance costs for the equalization system at Ypsilanti Township are not monitored separately and are therefore difficult to estimate. It is the authors' observation that a negligible amount of operator time is required on a day-to-day basis for routine maintenance and operation. The only significant requirements will be for periodic repair of equipment and control systems. After three years of operation at Ypsilanti Township, the only equipment failure has been with the automatic valve following the equalization pump.

The electrical power supply and electrical facilities operations at the Ypsilanti Township Treatment Plant preclude the separation of power costs on a Plant No. 1 and Plant No. 2 basis. Thus, a true power cost comparison of equalized and unequalized flow conditions could not be made. However, the use of theoretical power associated expressions for equalized and unequalized flow conditions[20] indicated that the use of flow equalization at Ypsilanti Township does not result in power cost economies. Computations indicated that the savings in demand charges for aeration and return sludge pumping brought about by equalization were slightly less than the added power costs of the equalization pump and equalization basin blowers. Comparison of the theoretical power costs for equalized and unequalized flows are shown in Table 17.

TABLE 17

EFFECTS OF EQUALIZATION ON ANNUAL PLANT OPERATING COSTS

Item	Equalized Flow Cost			Unequalized Flow Cost		
	Demand Charge	Annual Energy Cost	Total	Demand Charge	Annual Energy Cost	Total
Blowers	$6,070	$11,360	$17,410	$8,380	$ 9,780	$18,160
Sludge Return Pumps	709	1,669	2,378	787	1,649	2,436
Influent and Equilization Pumps	425	500	925	0	0	0
TOTAL	$7,184	$13,529	$20,713	$9,167	$11,449	$20,616

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APPENDIX

MEASUREMENT OF DATA VARIABILITY

A large volume of bihourly and daily data was collected in this study. In analyzing these data it was considered desirable not only to compare the average or mean values of the waste parameters in different process streams, but also the variability or scatter of the data used to compute the mean values. Three related measures of scatter were employed, the variance, standard deviation, and coefficient of variation.

If $X_1, X_2, \ldots X_n$ is a sample of n measurements having a mean of $\bar{X}$, the standard deviation S of the sample is defined by

$$S = \left[\frac{1}{(n-1)} \sum_{i=1}^{n} (X_i - \bar{X})^2 \right]^{\frac{1}{2}}$$

The quantity S^2, the square of the standard deviation S, is called the variance of the sample. The coefficient of variation is simply the standard deviation S divided by the mean $\bar{X}$.

The standard deviation can be compared with the mean of the variable parameter to provide an individual with a feeling of the degree of uncertainty associated with the variable parameter. The variance allows the individual to ascertain the tightness of data distributions; smaller values implying data distributions less widely spread about the mean; greater values implying data distributions widely spread about the mean. The coefficient of variation indicates the data scatter as a fraction of the mean and can thus be used to compare the scatter of data having different mean values.

DATA LISTING

Experimental data analyzed in this report are listed on the following pages. Bihourly data (labeled as hourly data) are listed first, followed by daily data. Following are some notes of explanation for the abbreviations and shorthand notations used in the listing:

1. For the bihourly data, the four numbers in the left-hand column indicate the date and time of day of the sample; e.g., 1909 at the top of the first page indicates October 19, 9:00 a.m.

2. Daily data are listed chronologically beginning June 1, 1979 and ending July 31, 1979. The digits in the left-hand column indicate the month and day of the sample, e.g., 620 indicates June 20.

3. Special abbreviations used are as follow (general abbreviations and symbols are given at the beginning of the report):

RI	raw influent
EQ	equalization basin effluent
FE	final effluent
AS	aeration basin
SETTL	settleability (See Table 10)
APPL	applied air, cu ft[a]
R	recycle rate, %
TEMP	temperature, °F[b]

4. For the bihourly data, flows are given in mil gal/2 hr[c]; for the daily data flows are given in mgd[d]

5. Zeros in the data columns indicate no data

---

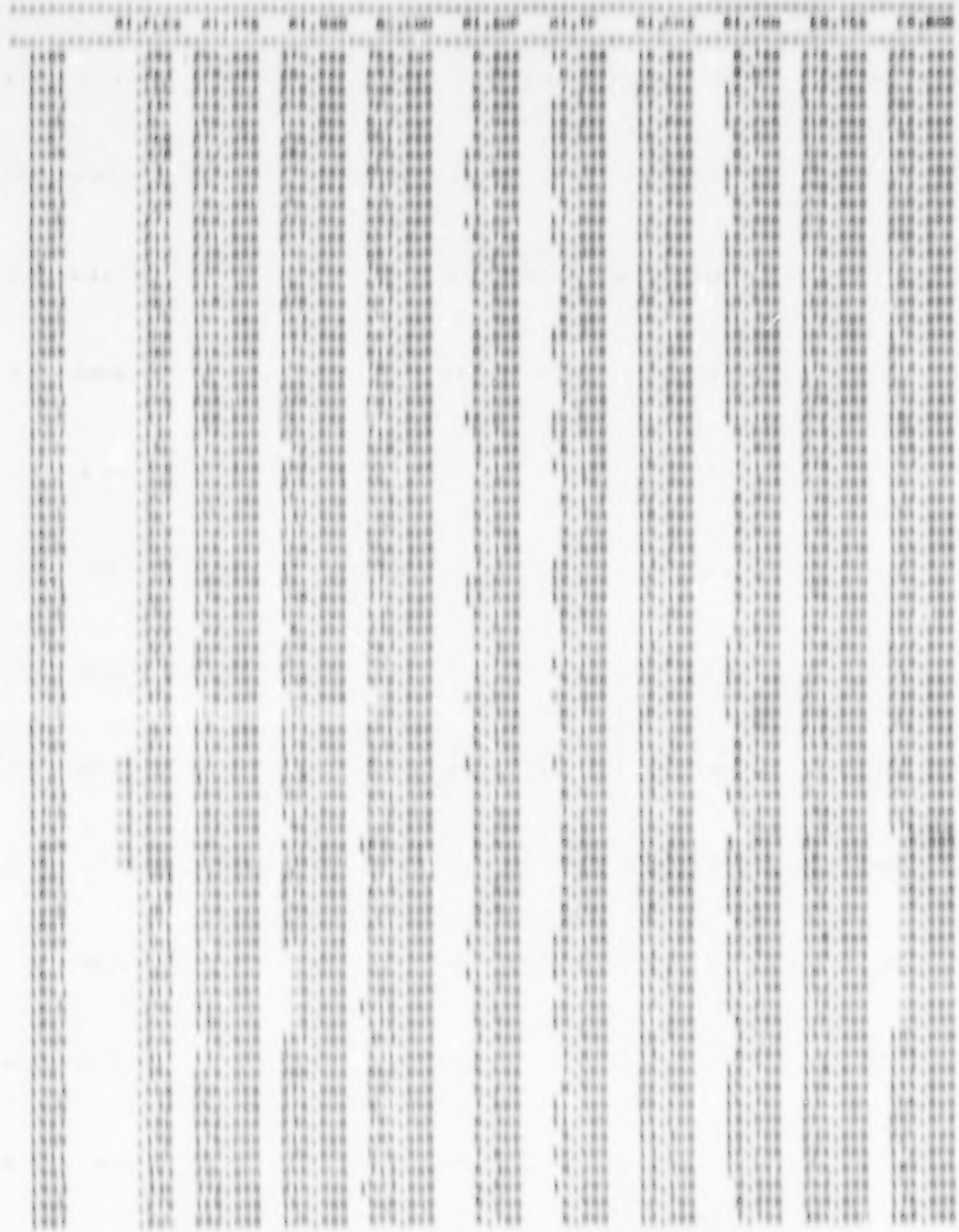
[a]cu ft x 0.028 = m^3

[b]0.555 (°F - 32) = °C

[c]mil gal/2 hr x 3,785 = m^3/2 hr

[d]mgd x 3,785 = m^3/day

PLOT 1:HOURLY DATA,OUTDOOR DATA



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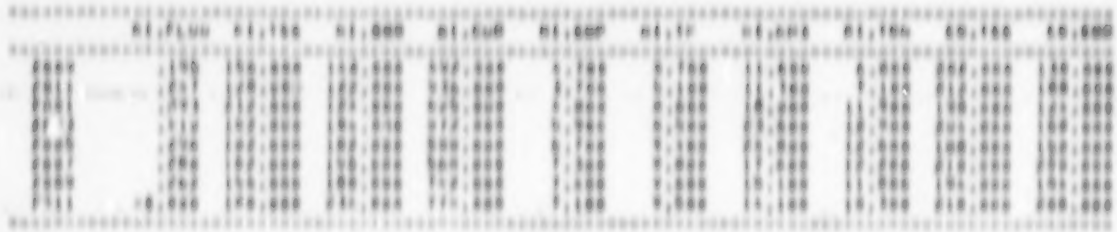

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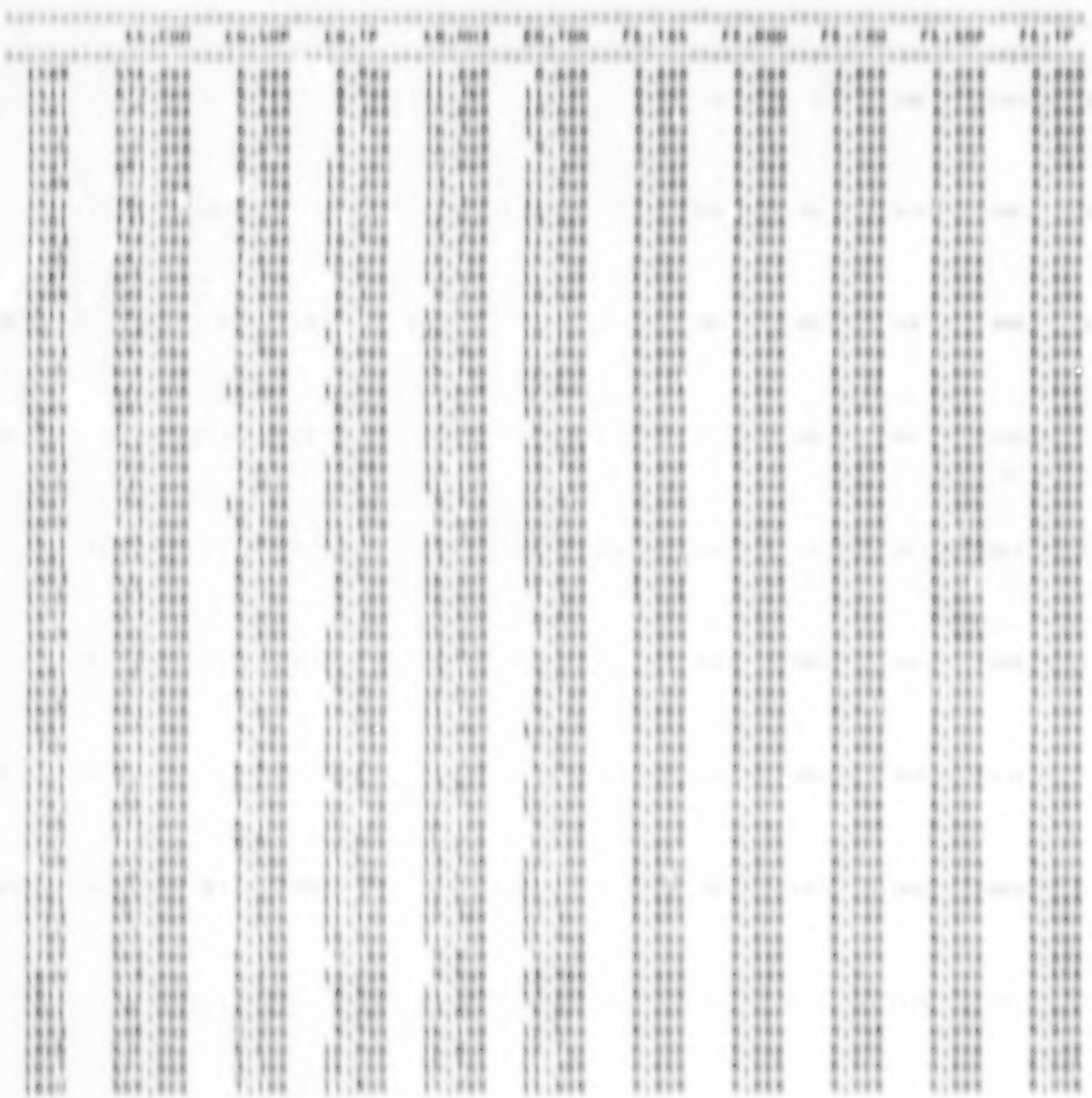

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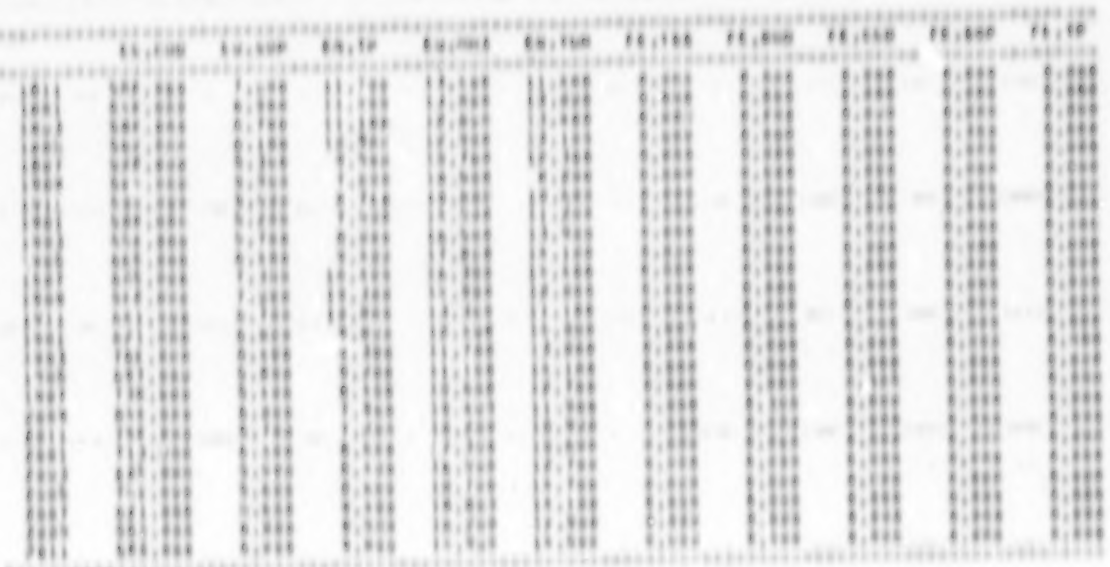
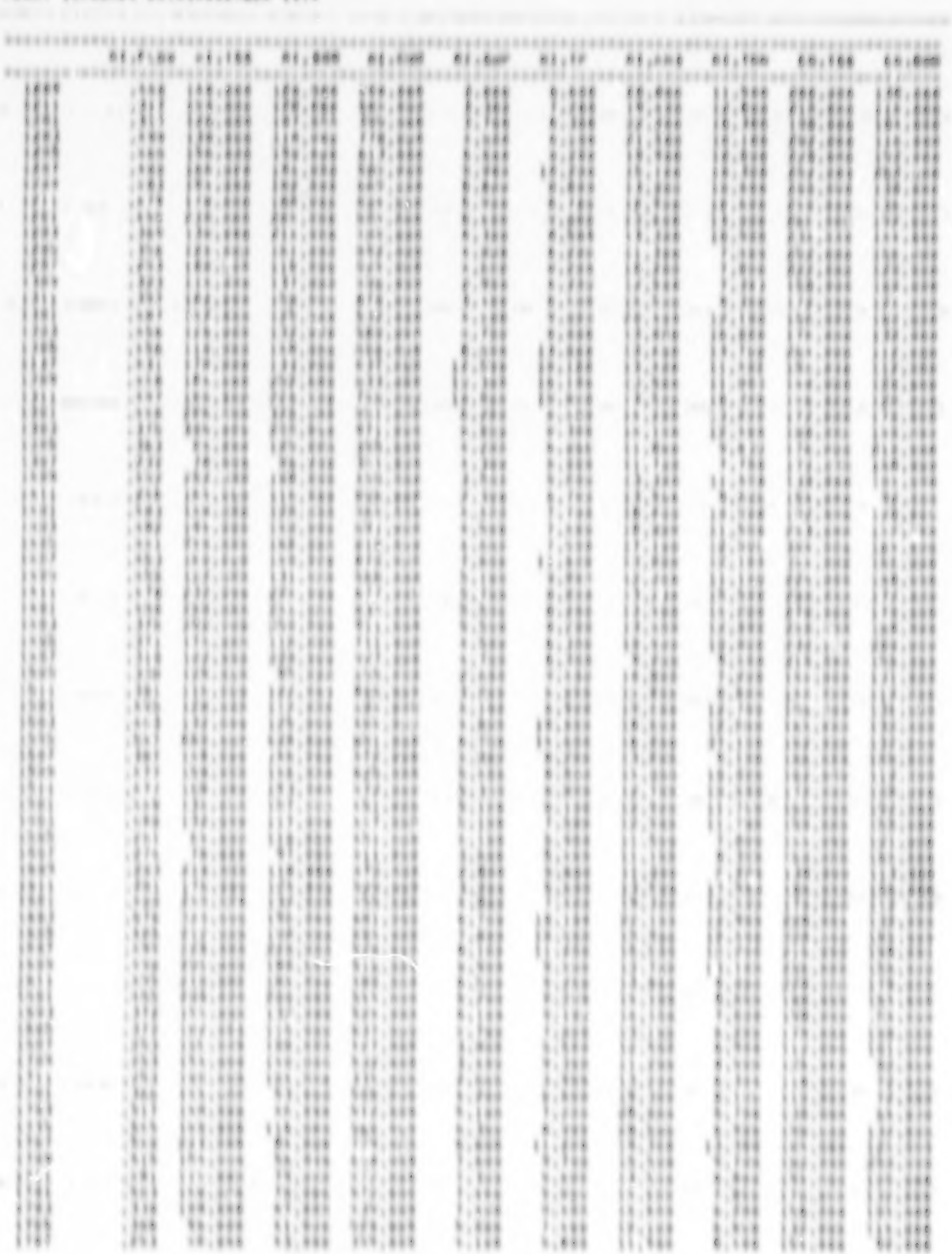
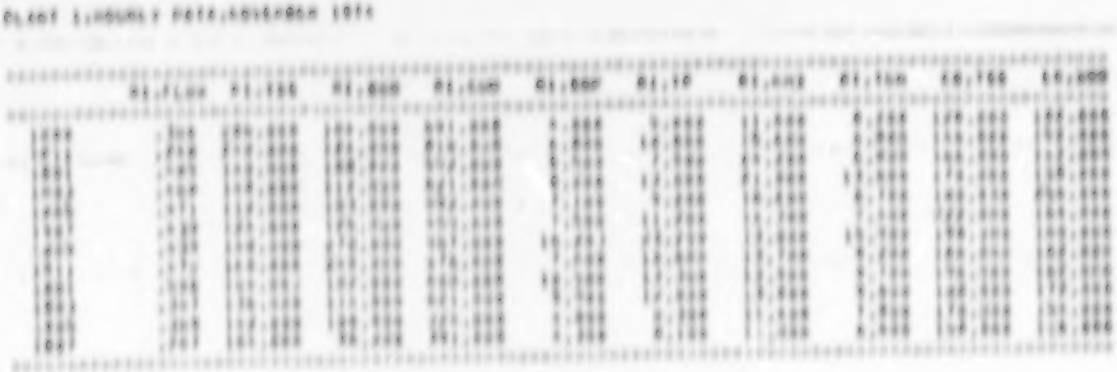
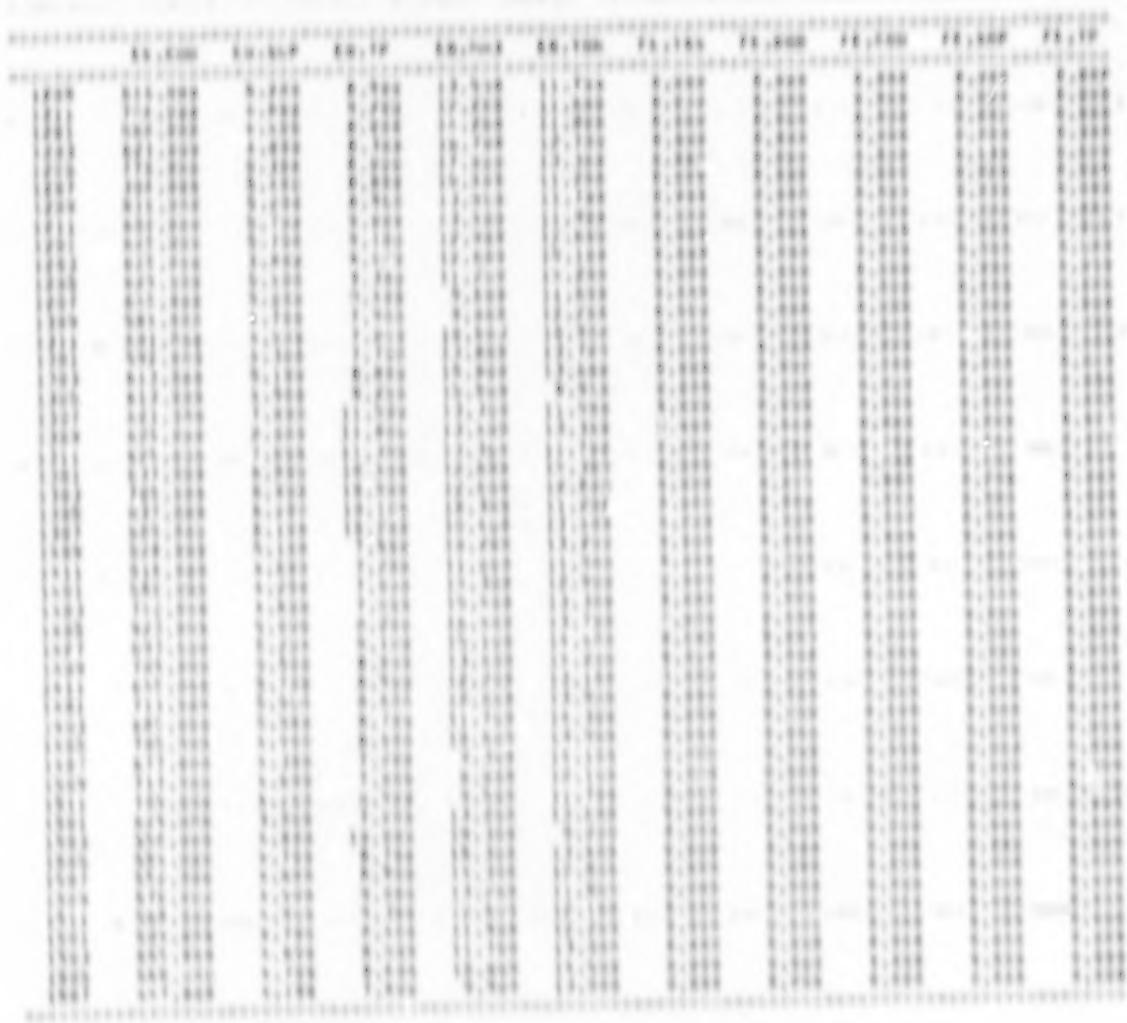


PLANT 1:HOURLY DATA,OCTOBER 1974

PLANT 1:HOURLY DATA,OCTOBER 1974







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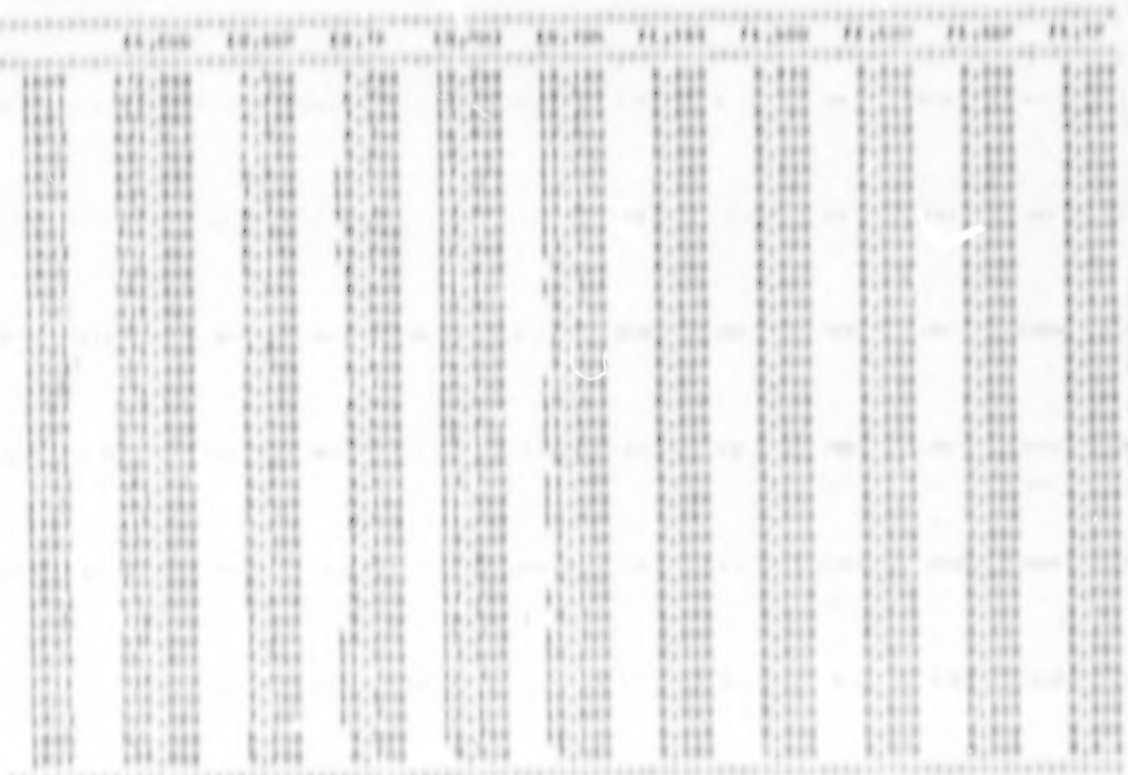
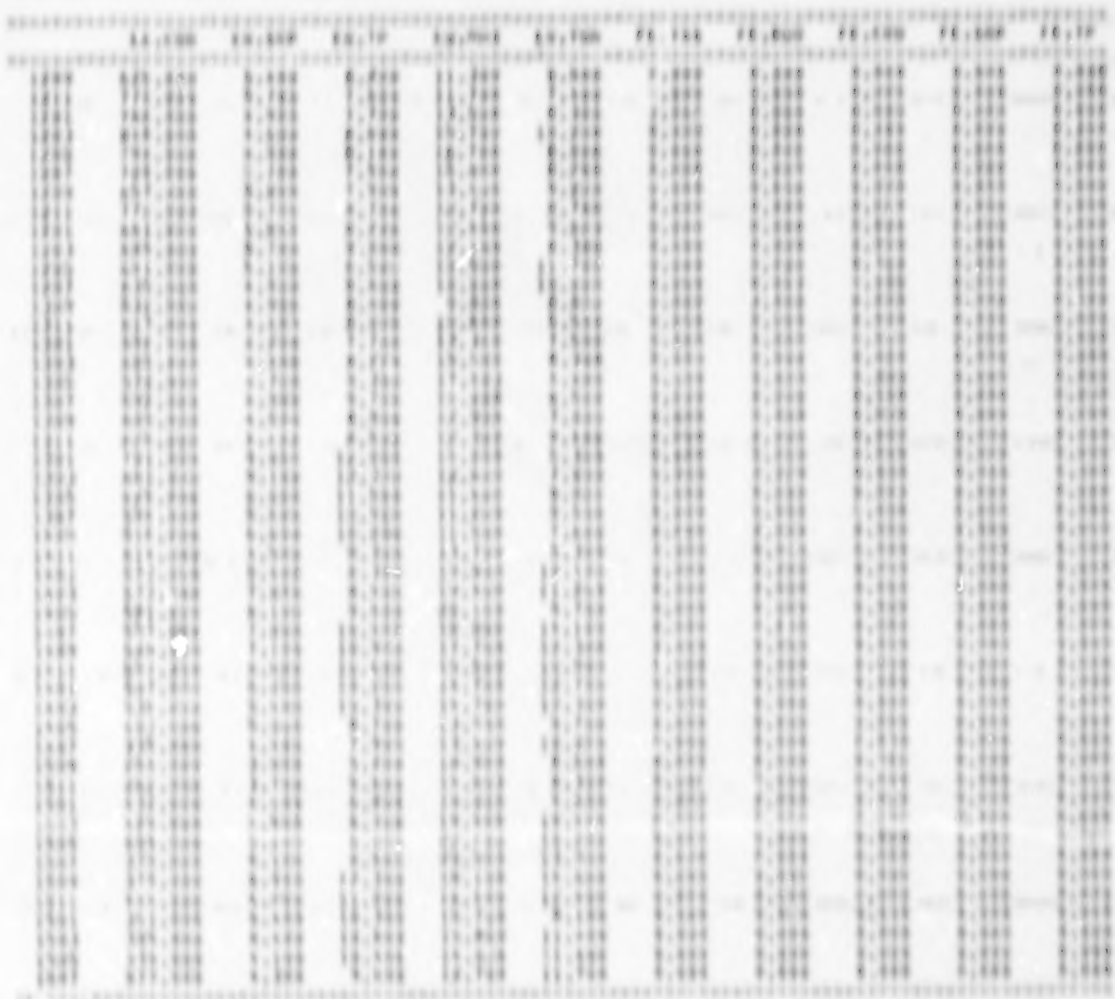
PLANT HOURLY DATA,NOVEMBER 1979



PLANT HOURLY DATA,NOVEMBER 1979

PLANT HOURLY DATA,DECEMBER 1974

PLANT HOURLY DATA,DECEMBER 1974



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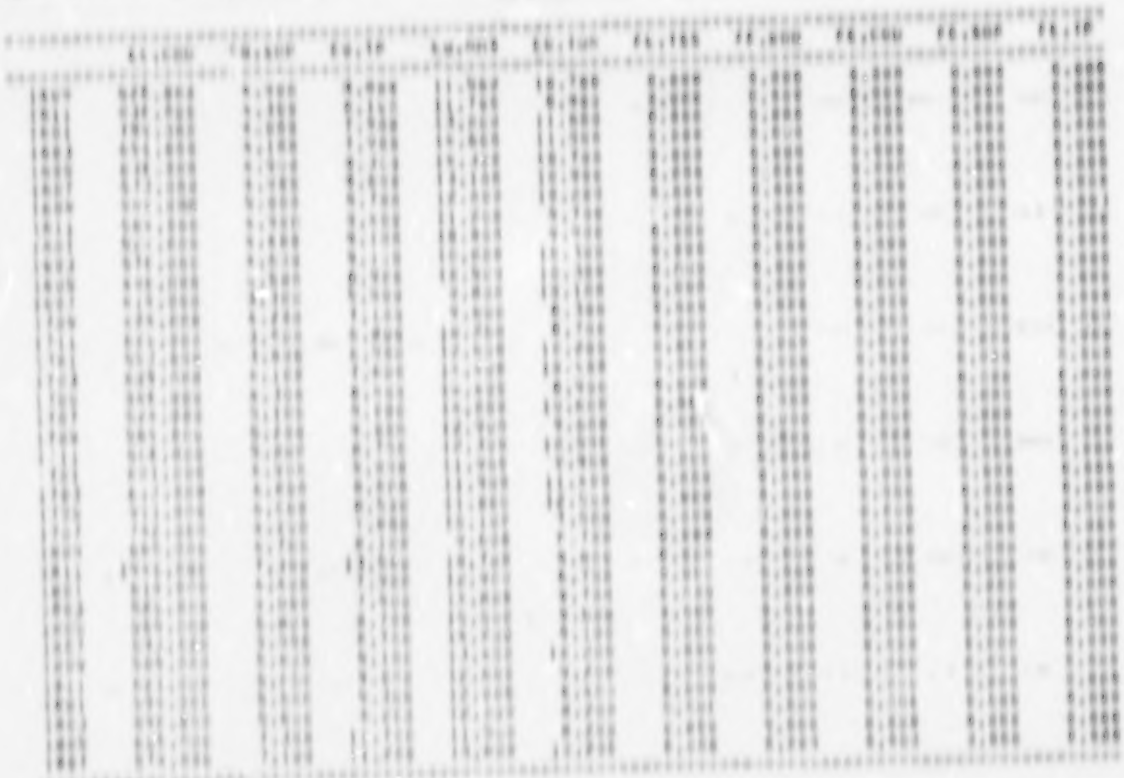
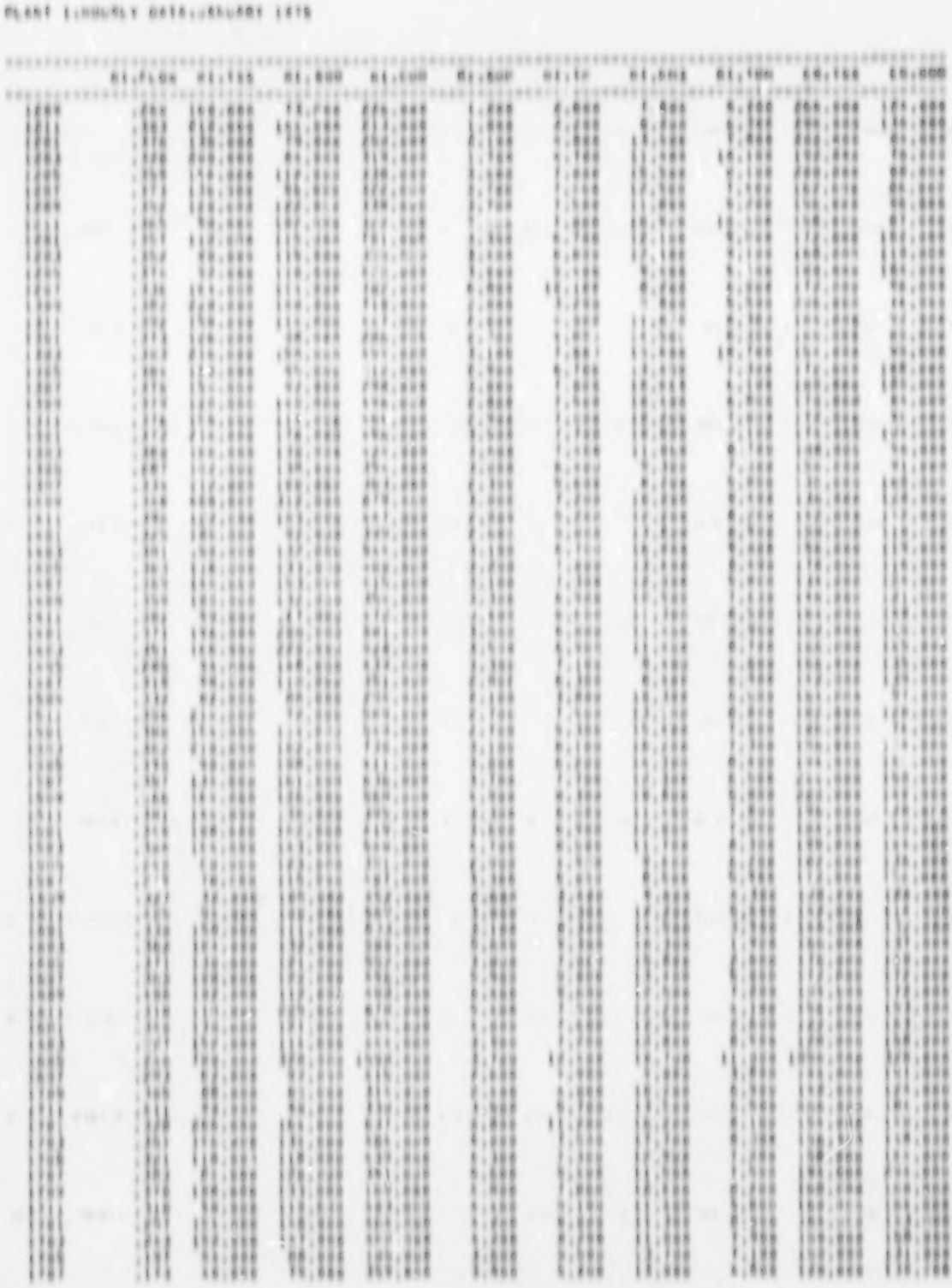
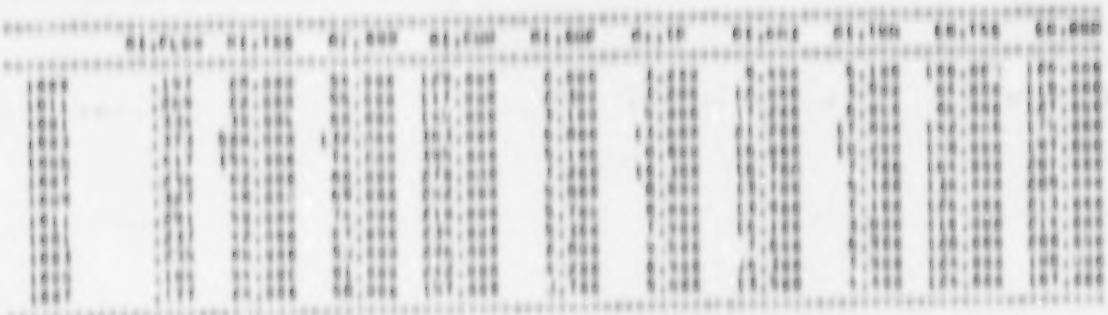


PLANT 1:HOURLY DATA:DECEMBER 1974 PLANT 1:HOURLY DATA:DECEMBER 1974



PLANT I/HOURLY DATA/JANUARY 1978



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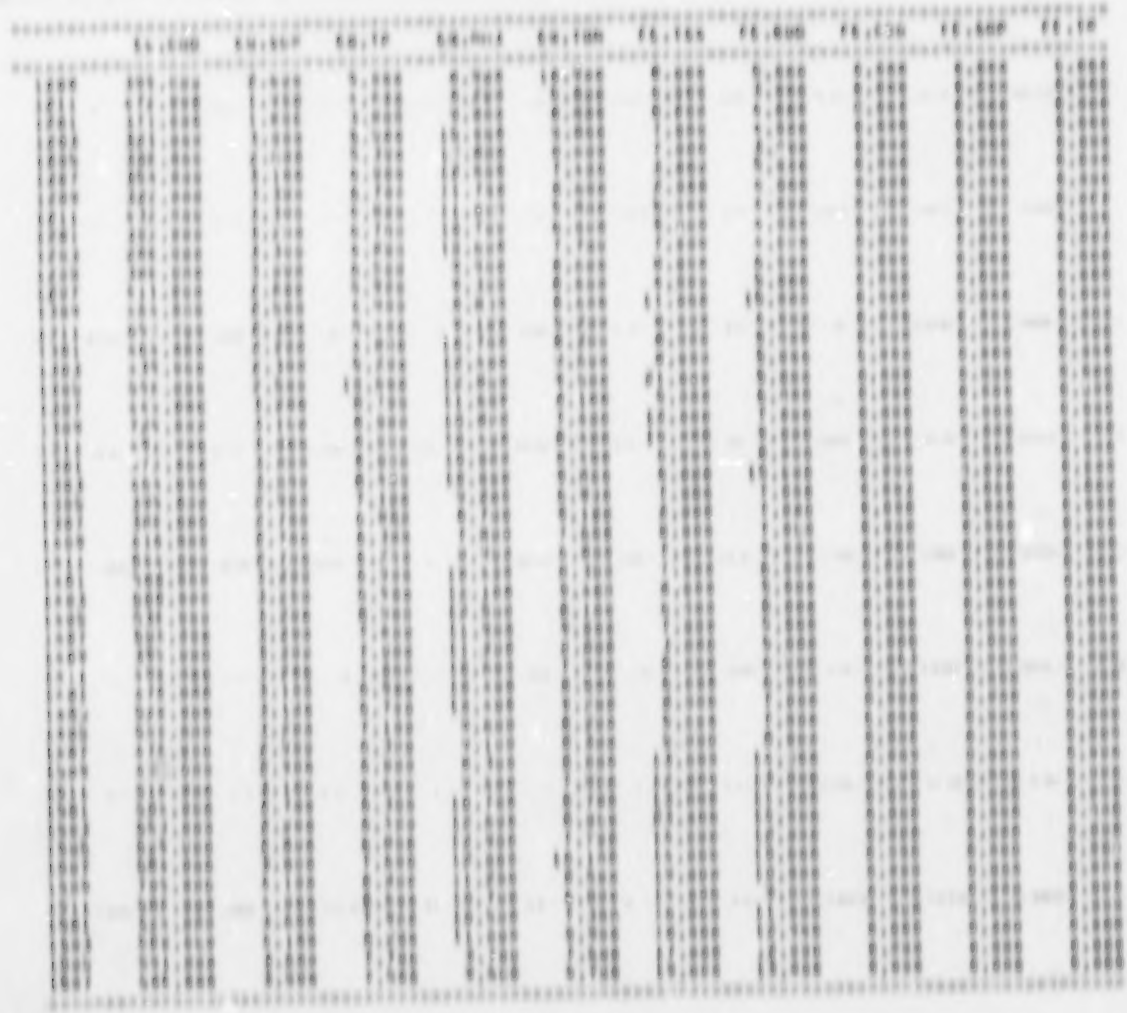

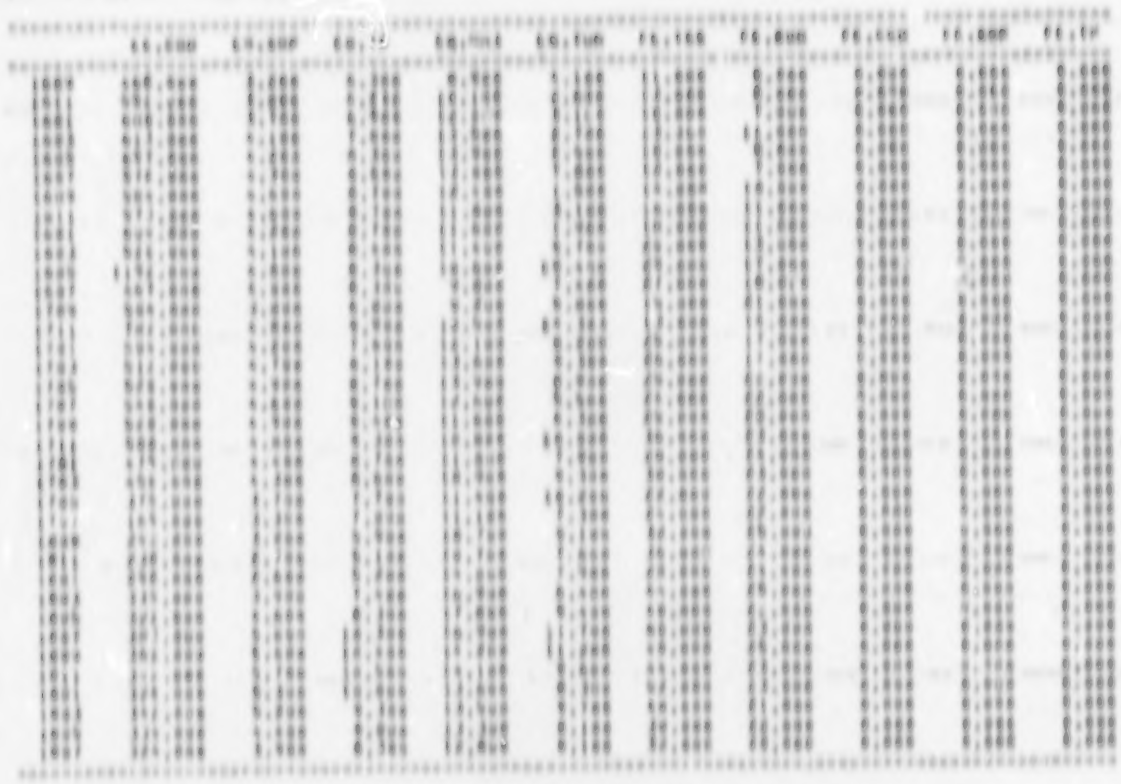

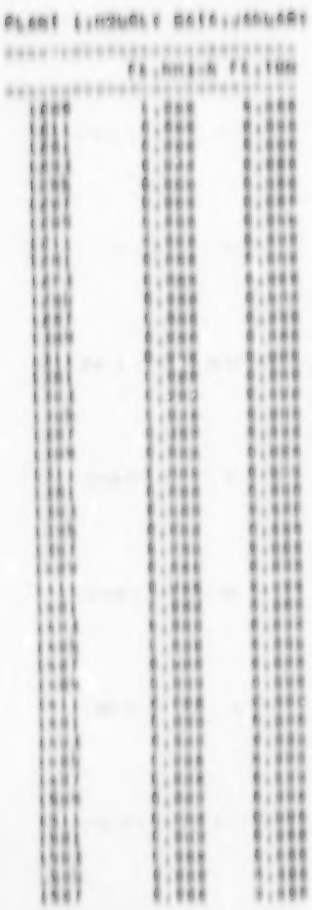

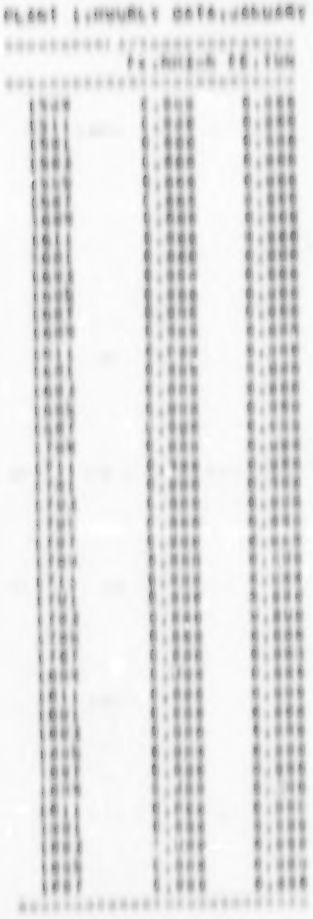

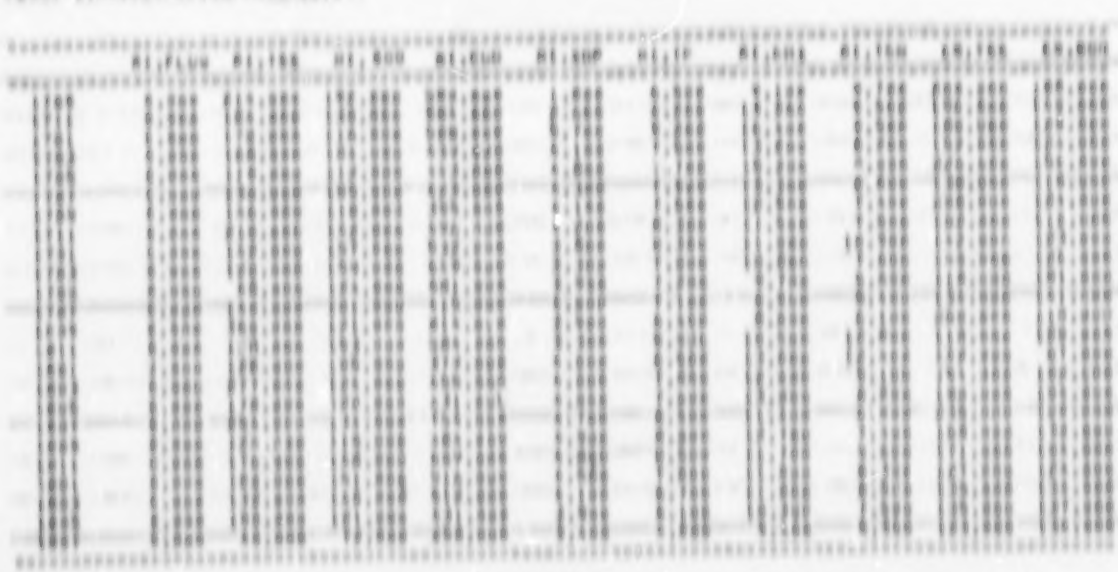

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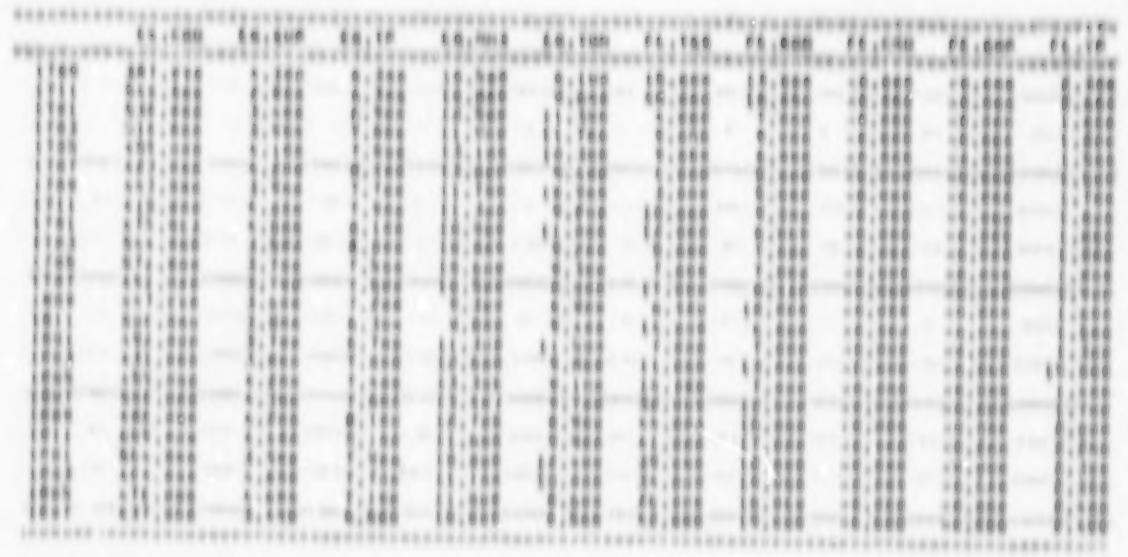

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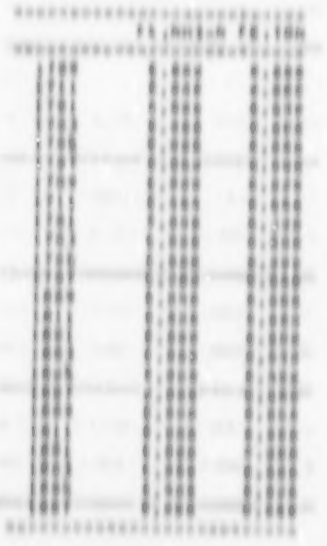

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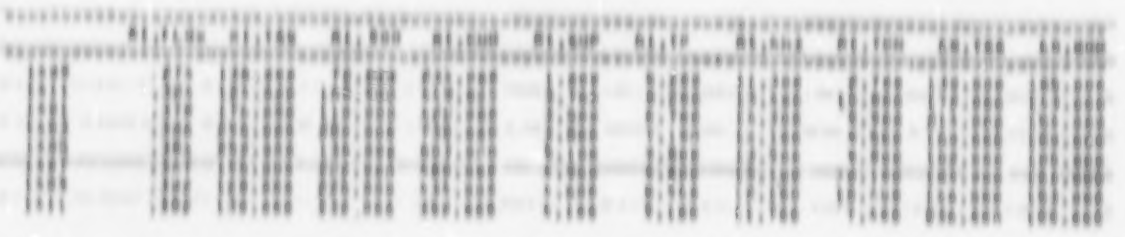

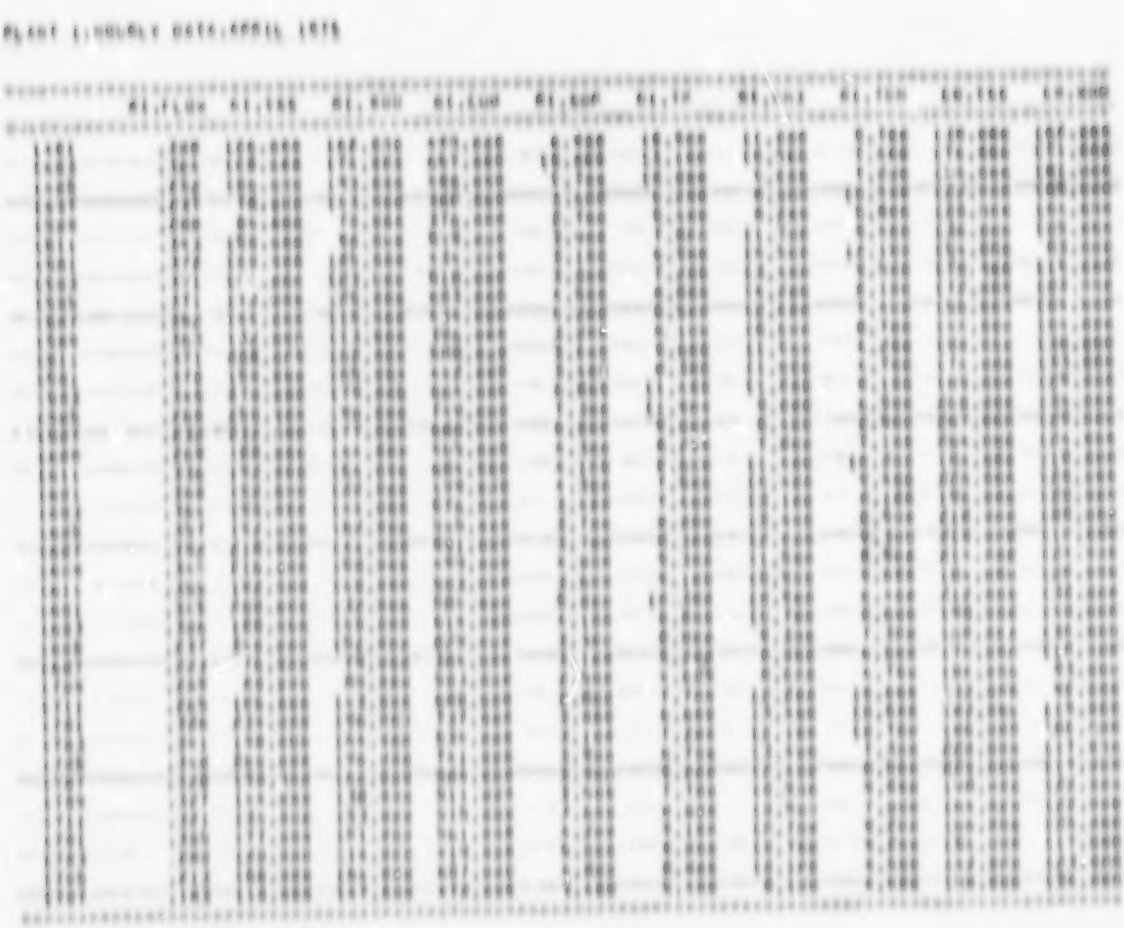

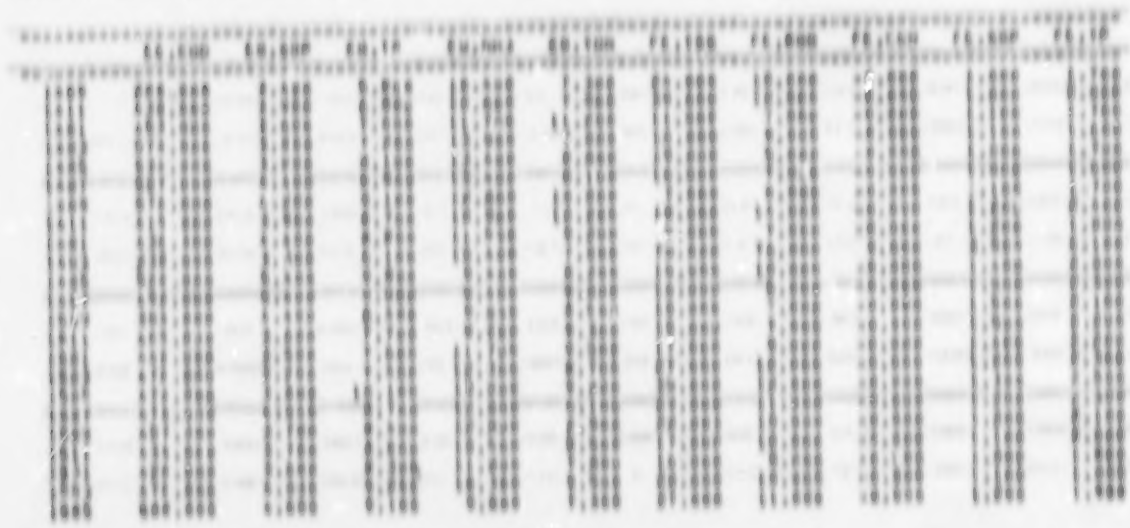

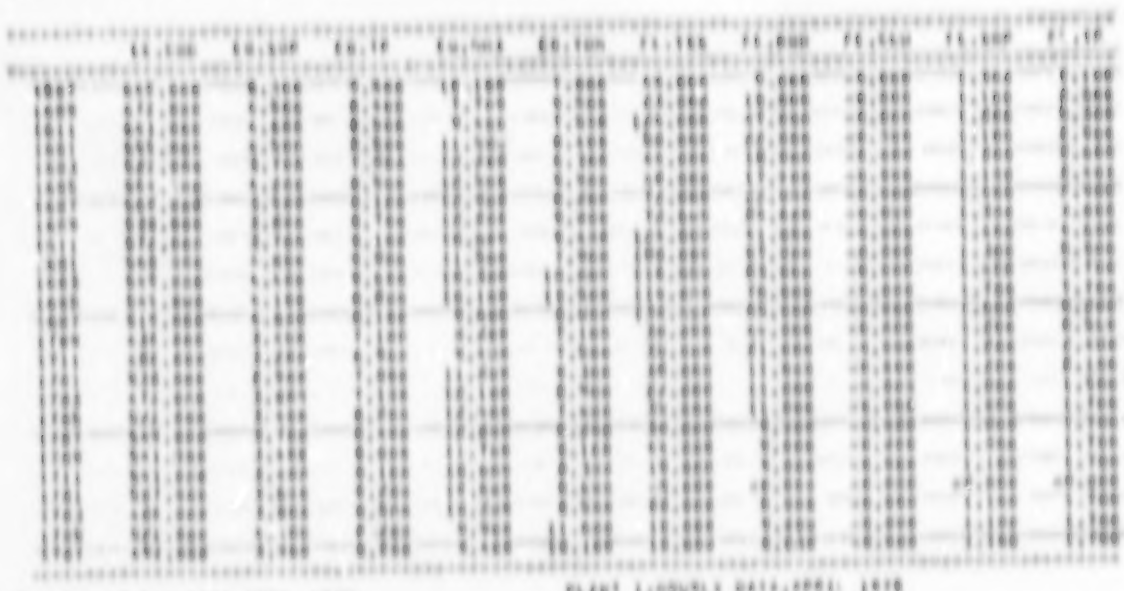

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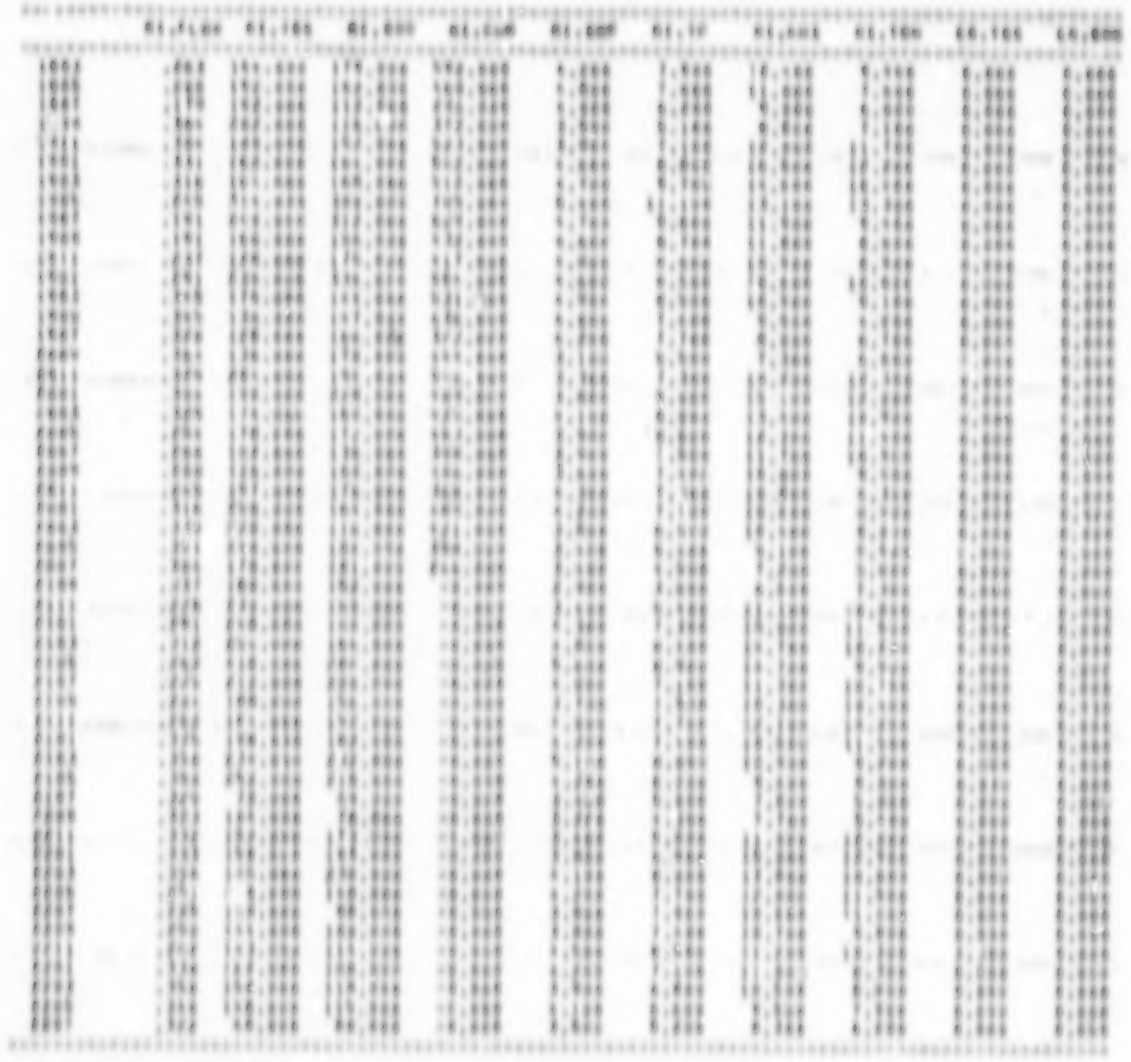

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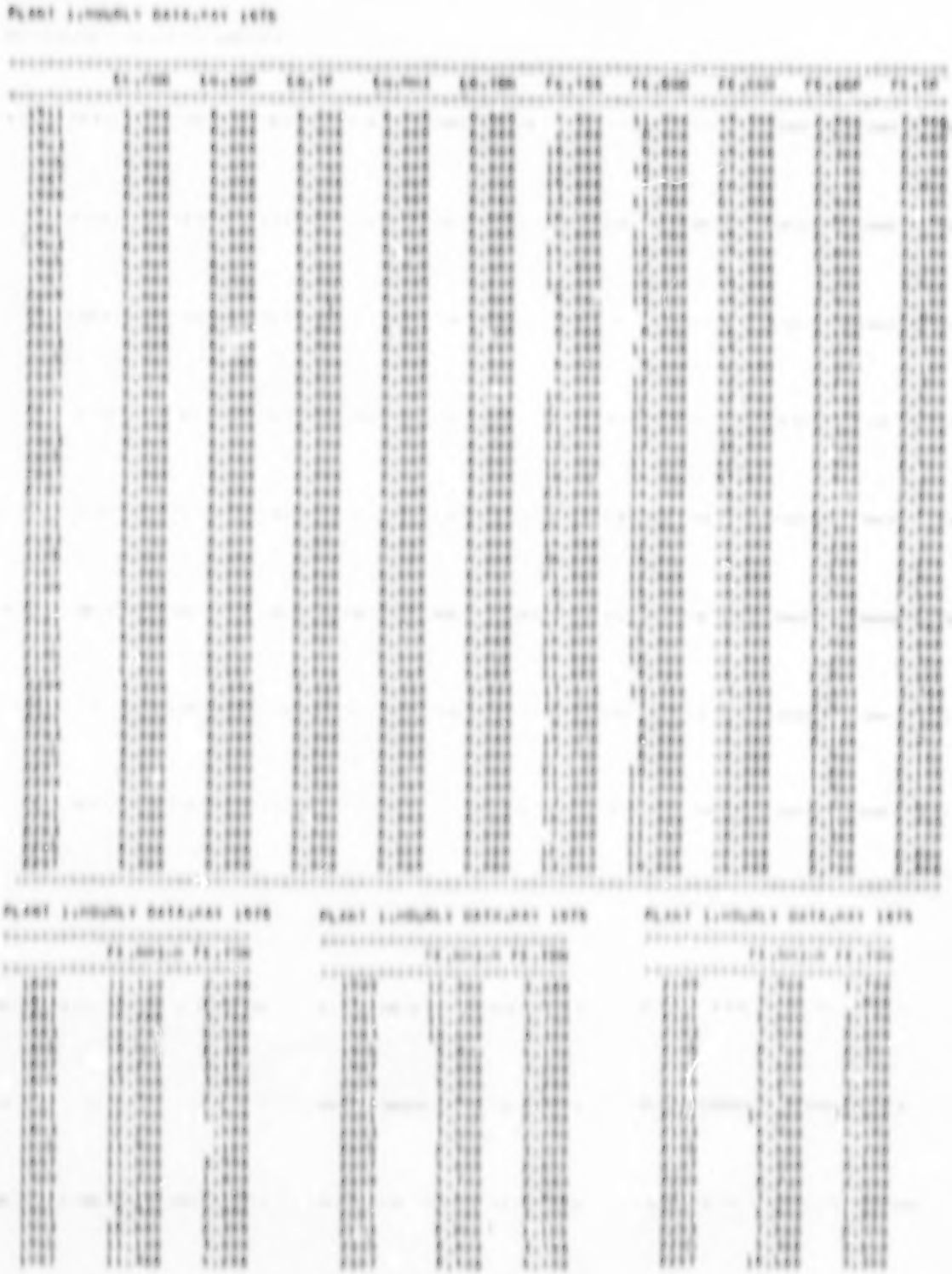
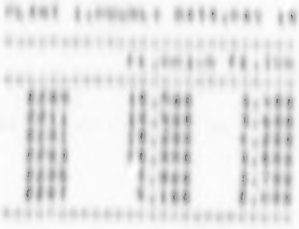
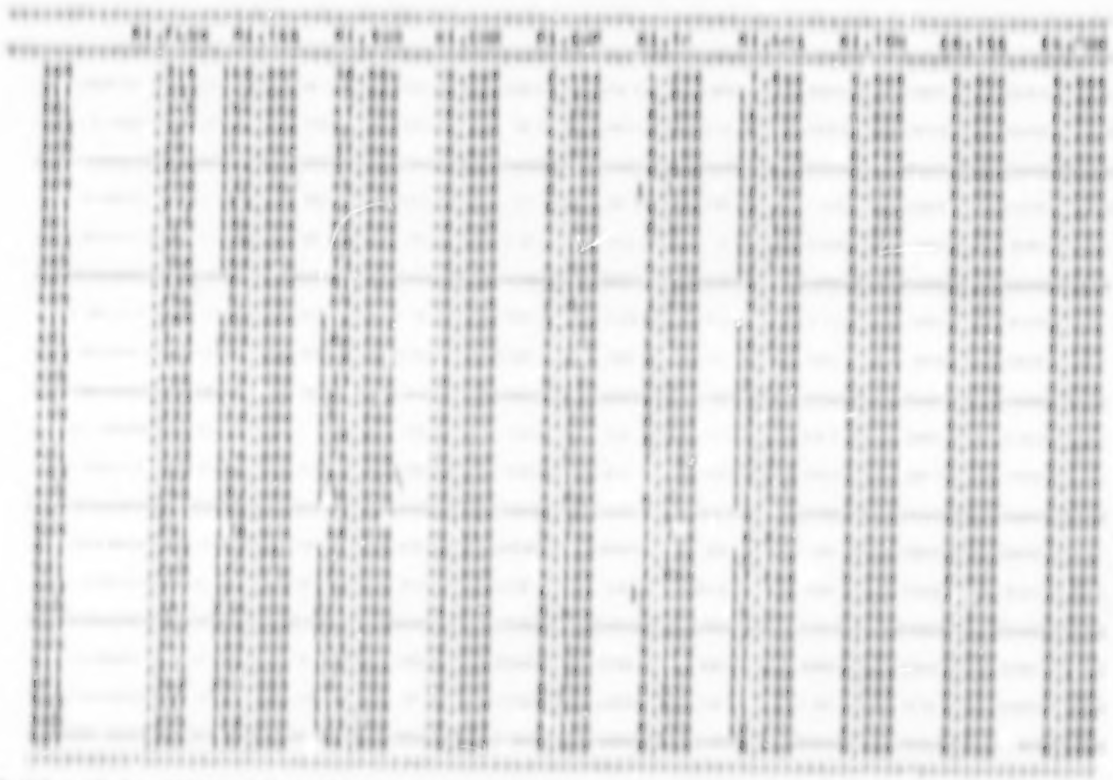
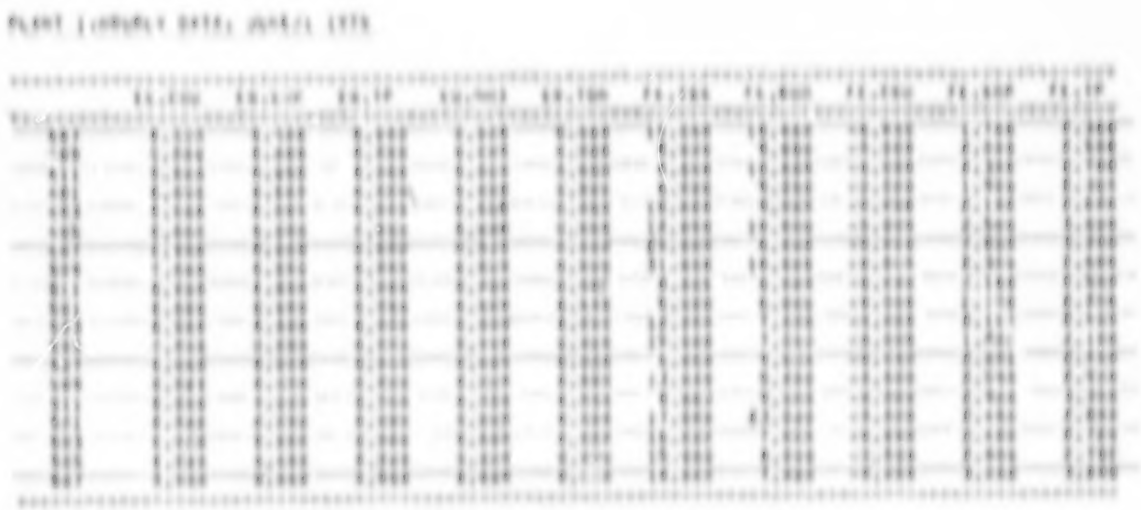
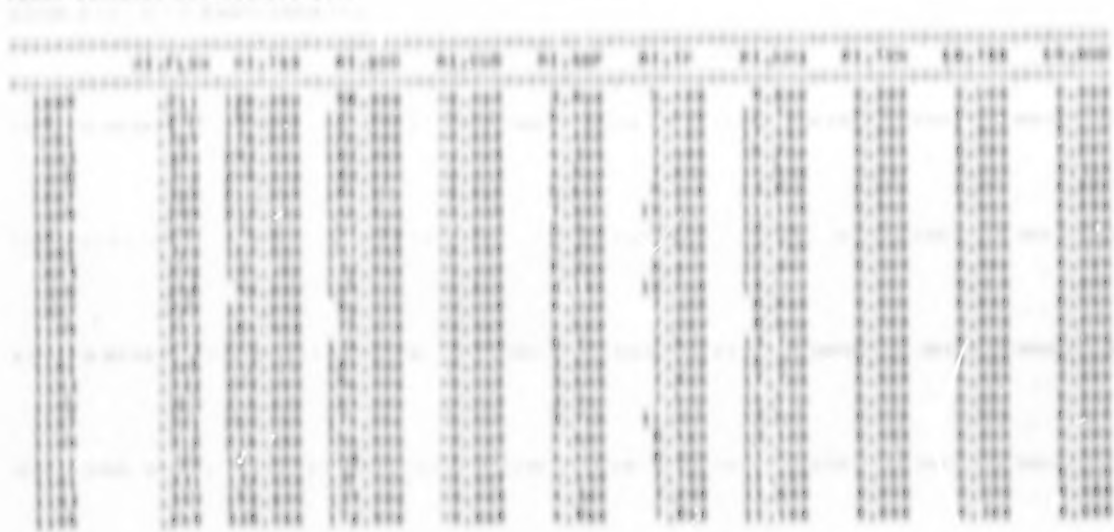


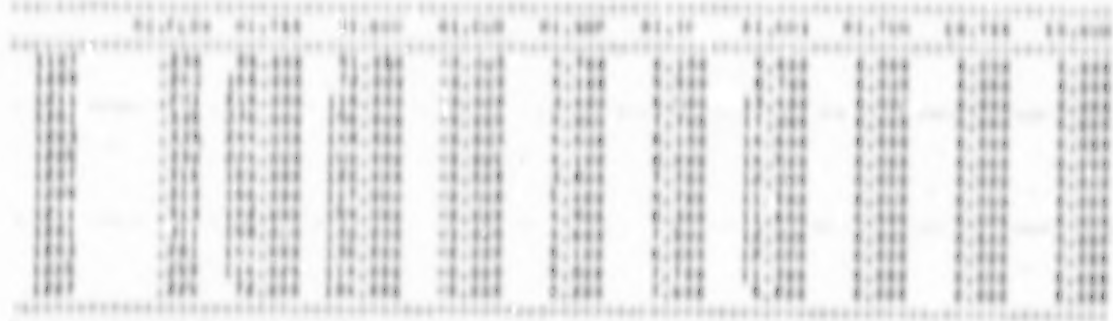








PLANT 1/HOURLY DATA/JUNE/2 1978



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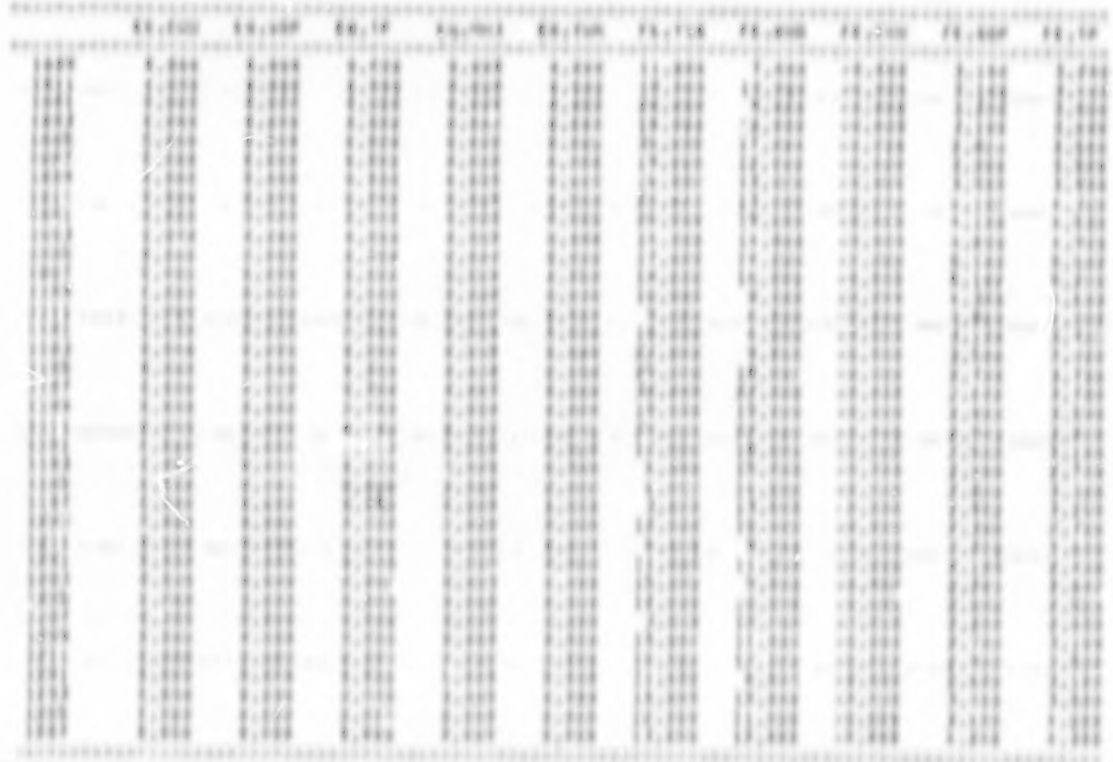

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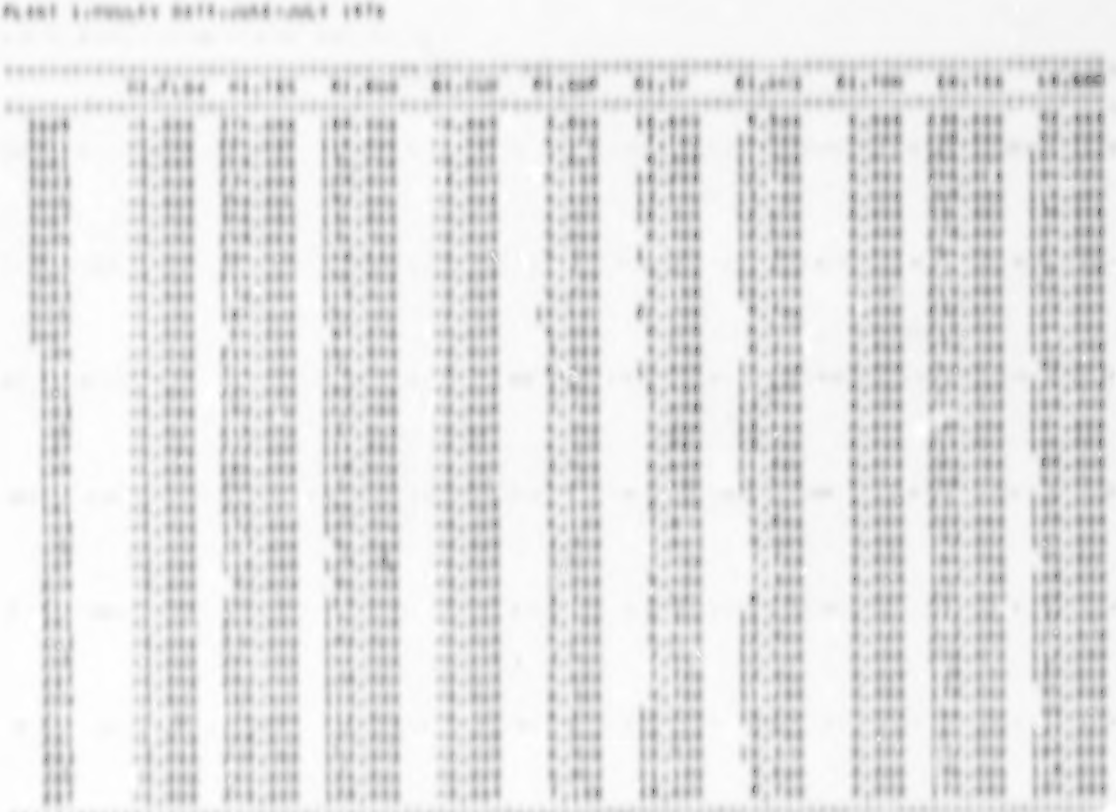
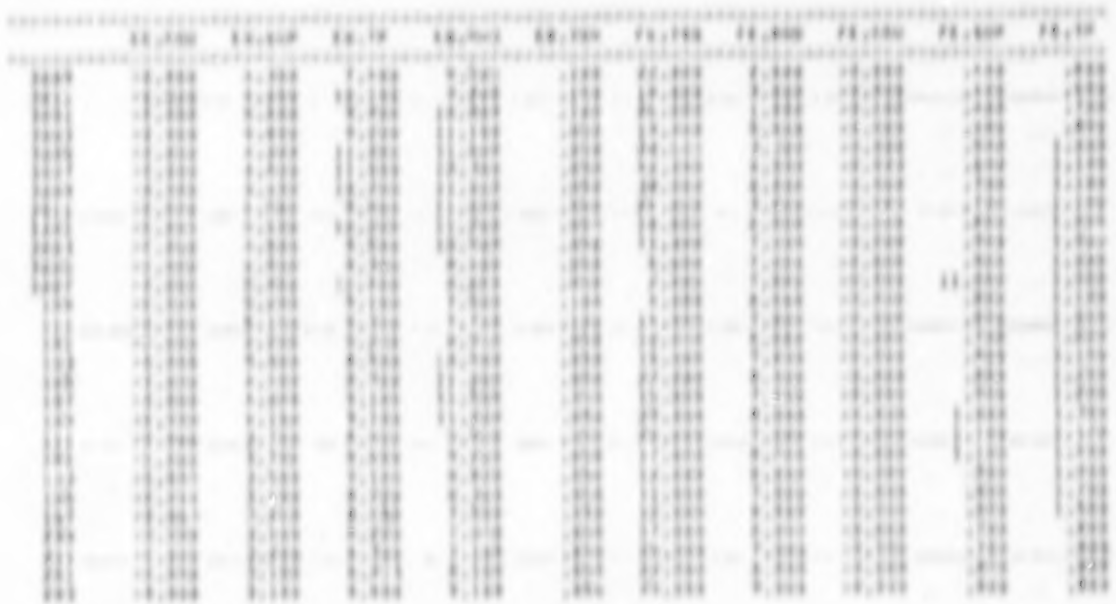
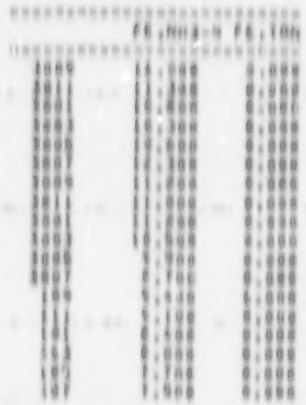




PLANT 1:HOURLY DATA:JUNE-JULY 1978

PLANT 1:HOURLY DATA:JUNE-JULY 1978



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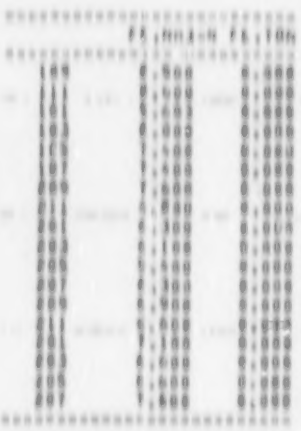

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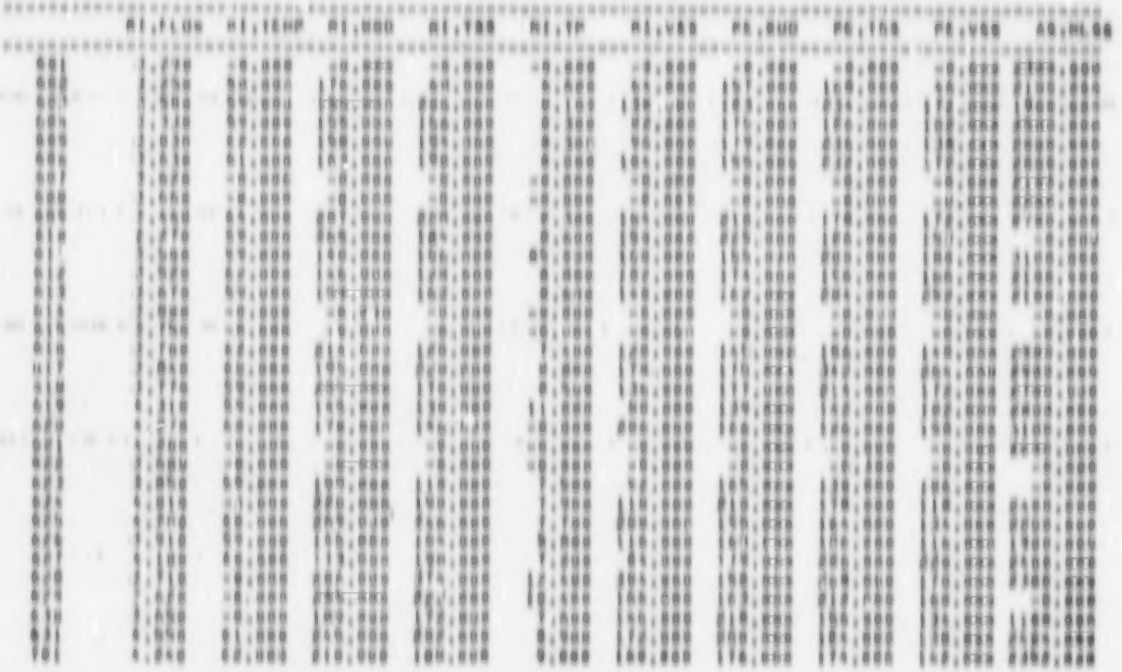

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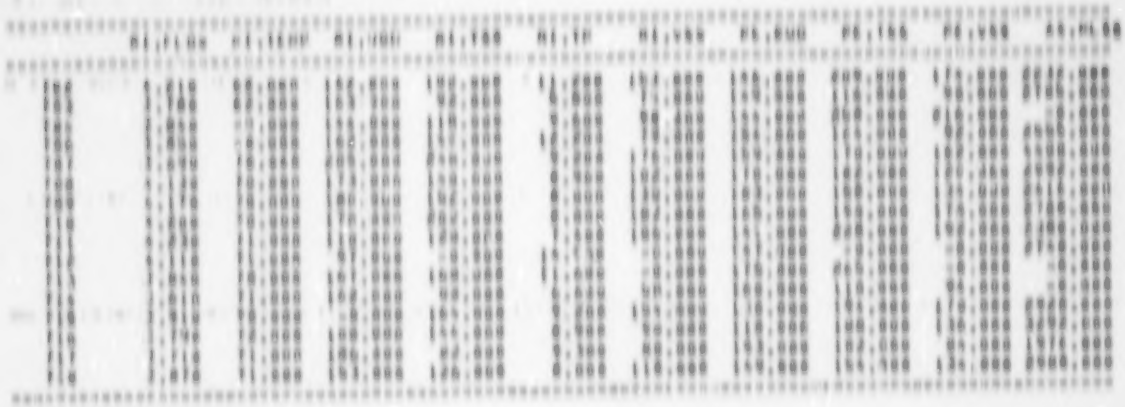

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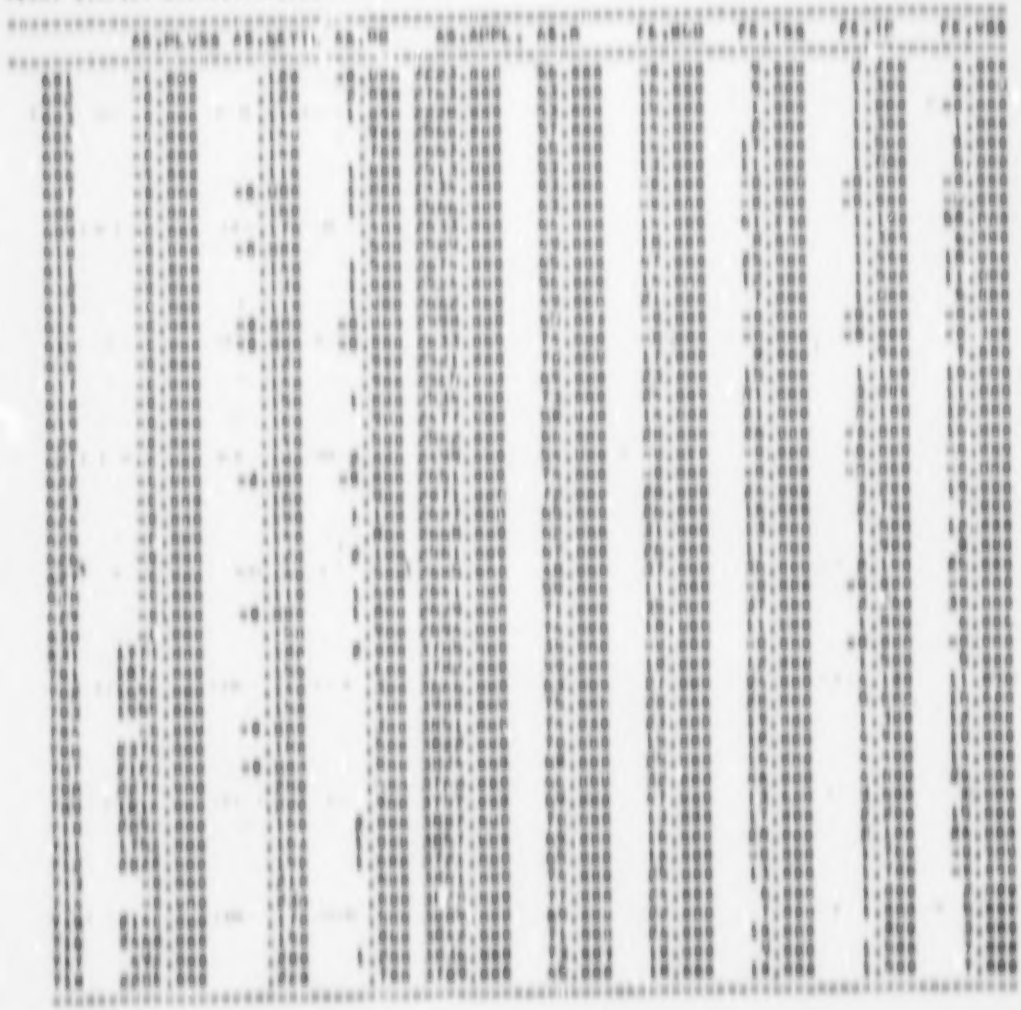

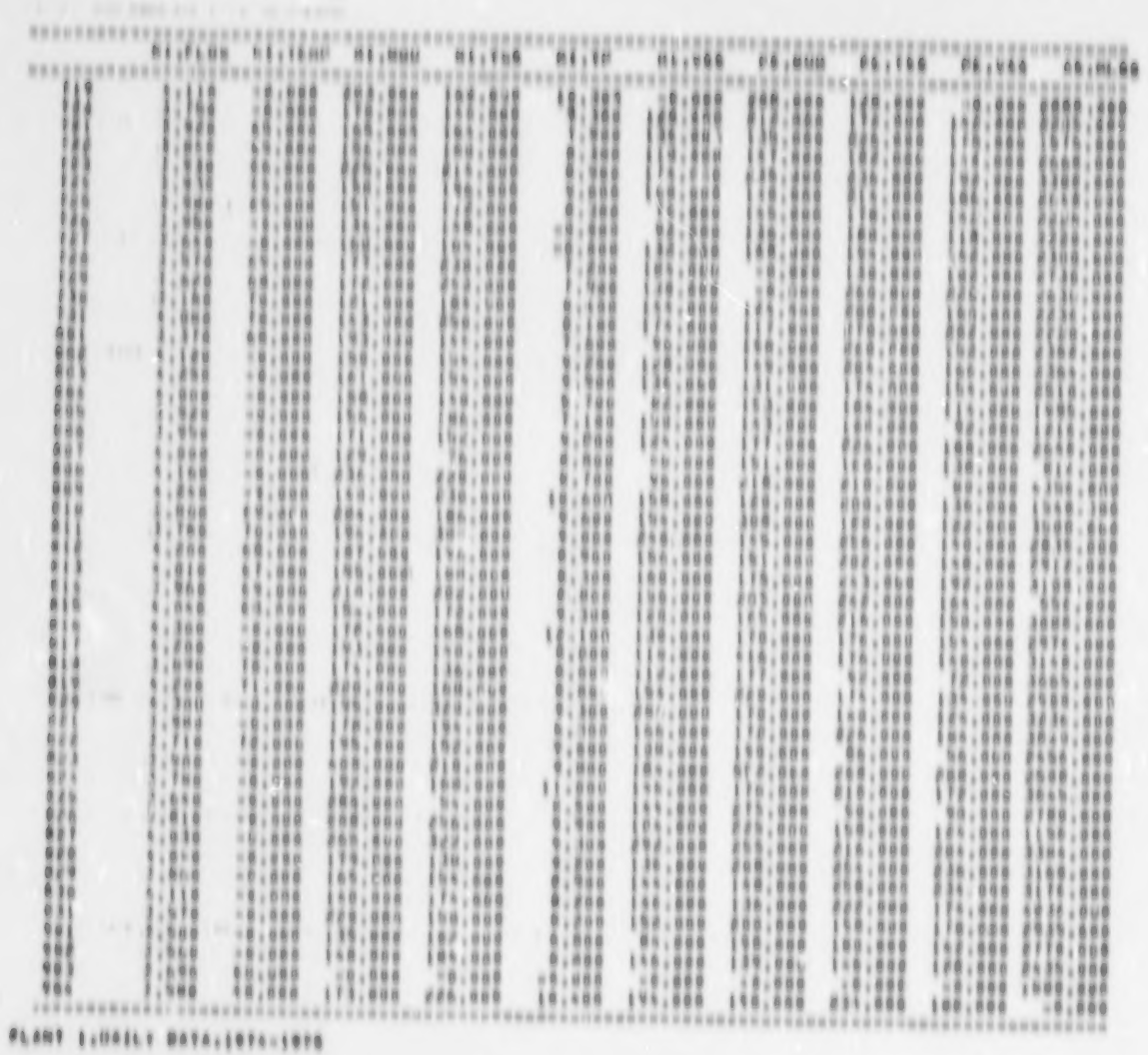

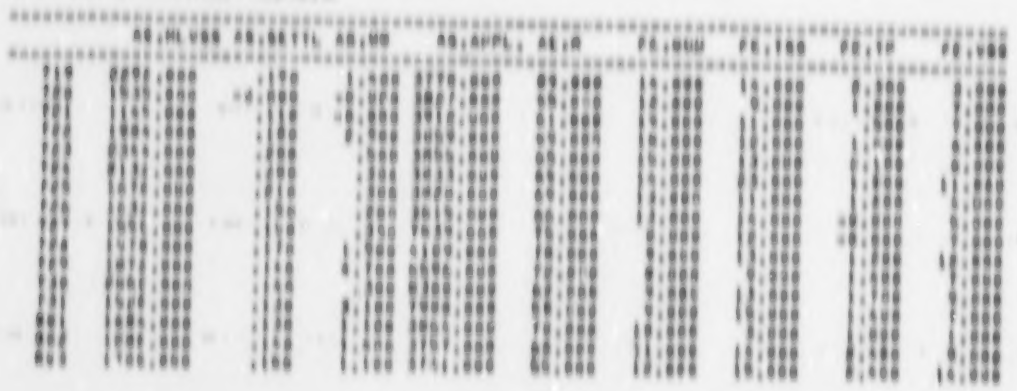

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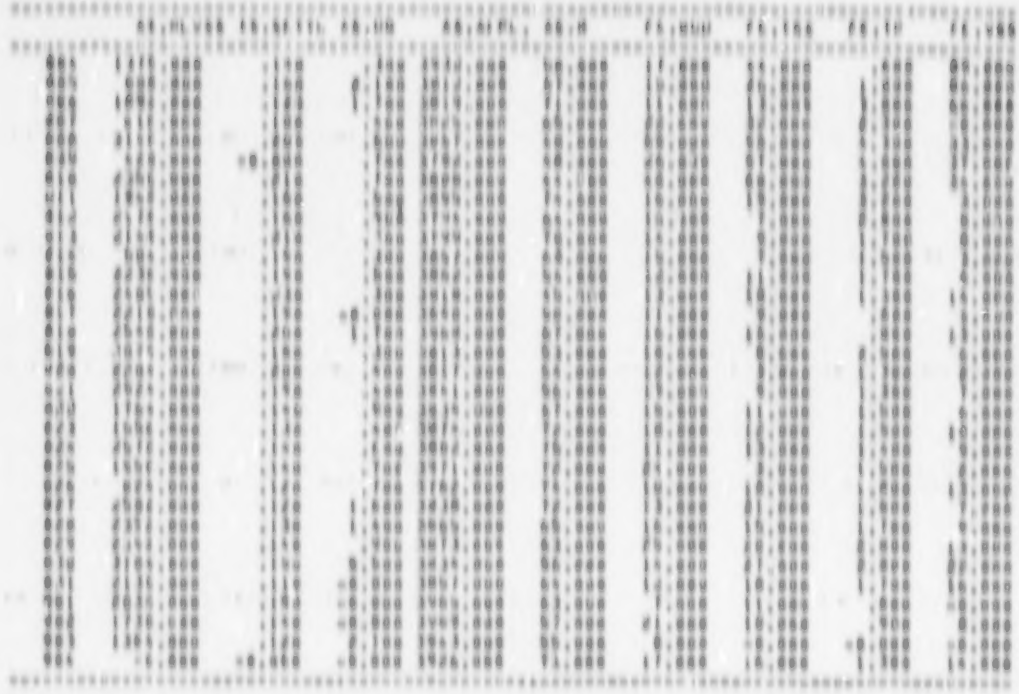

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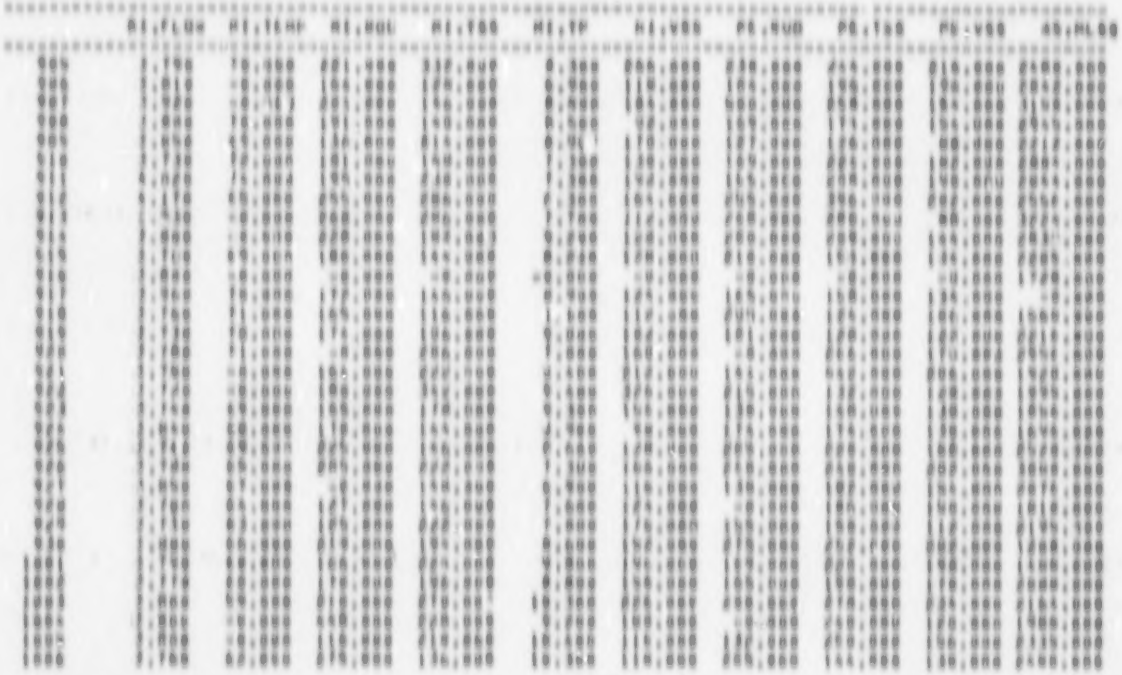

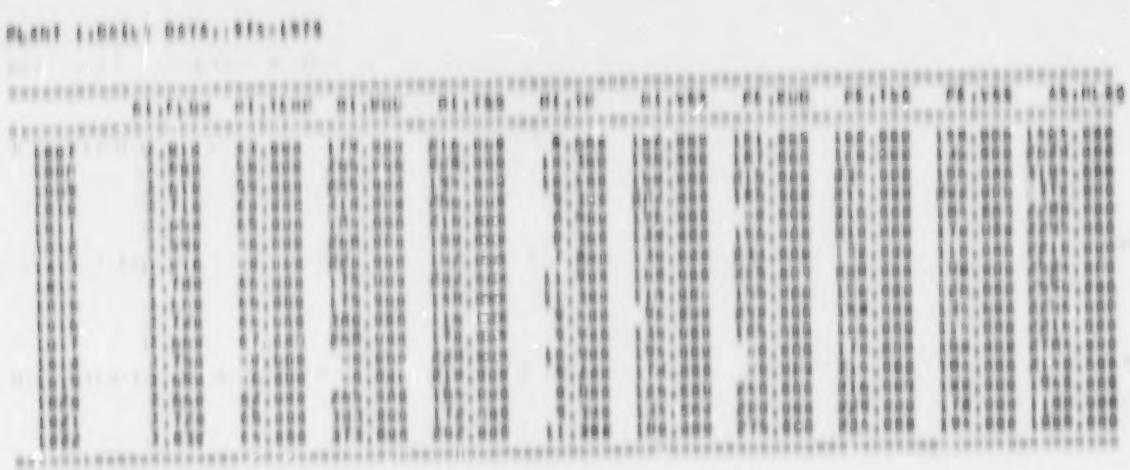

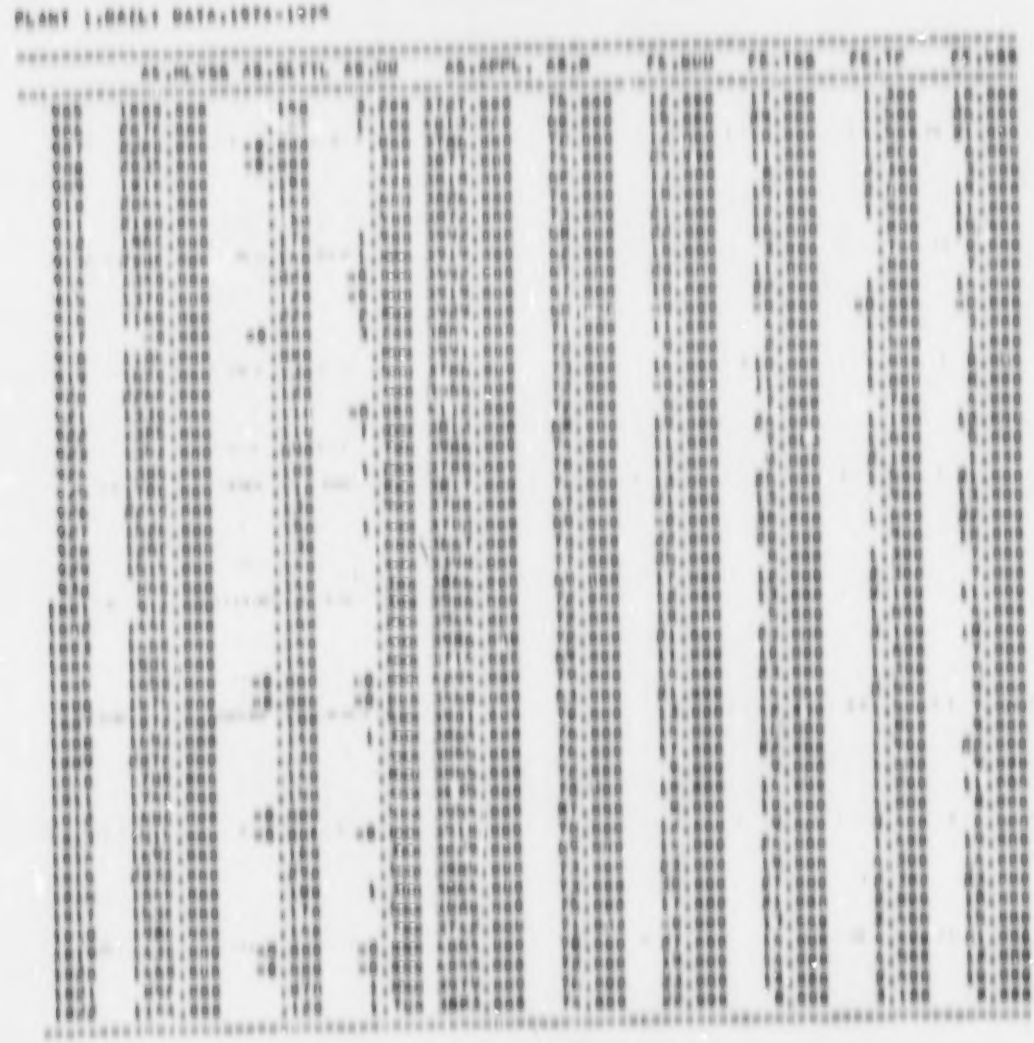

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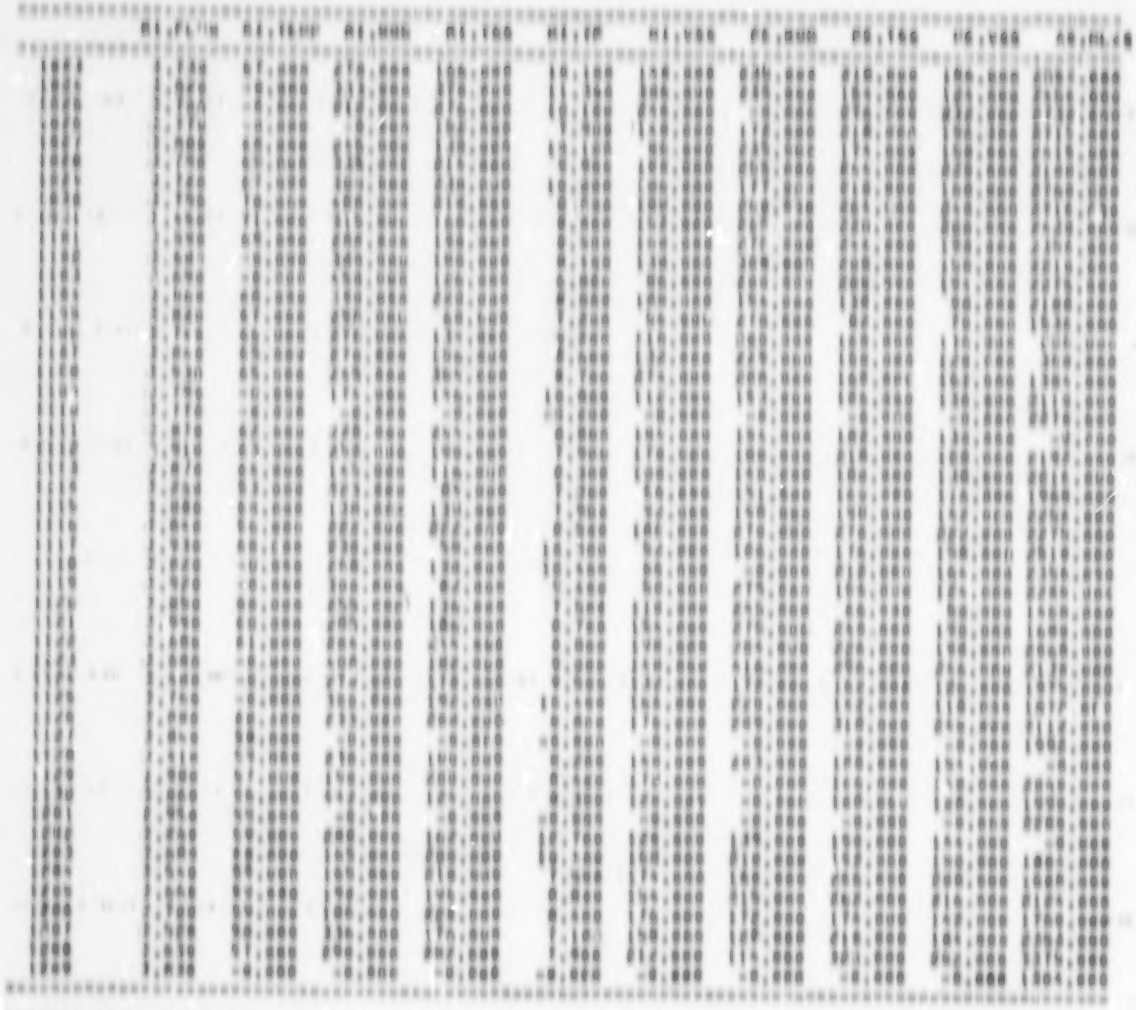
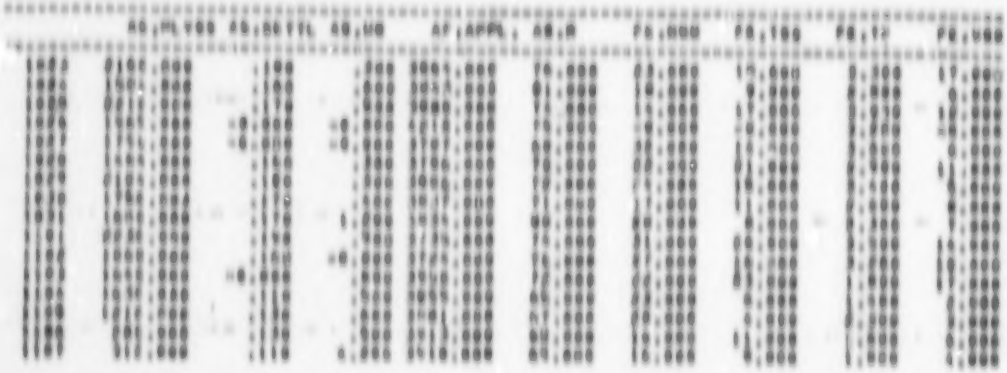


PLANT 1:DAILY DATA,1971-1972



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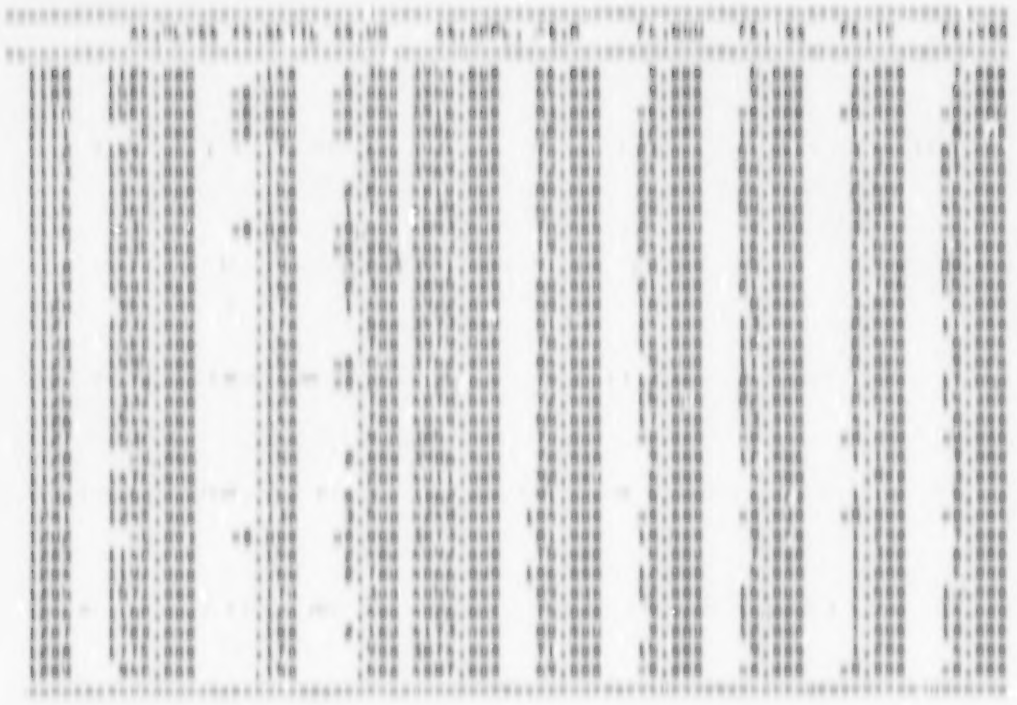

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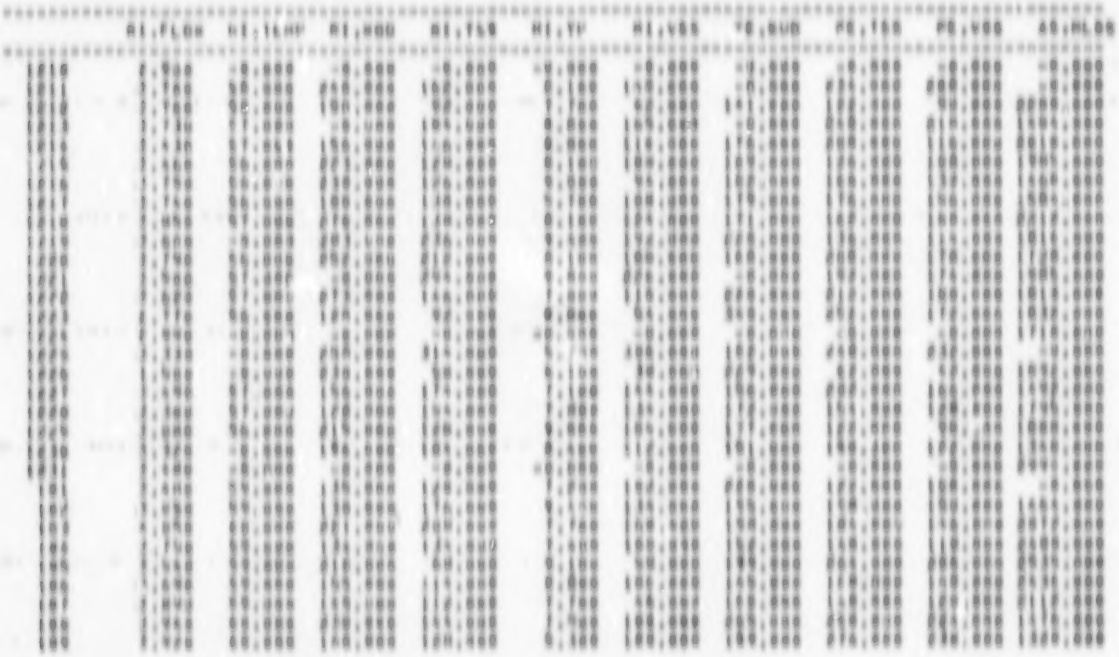

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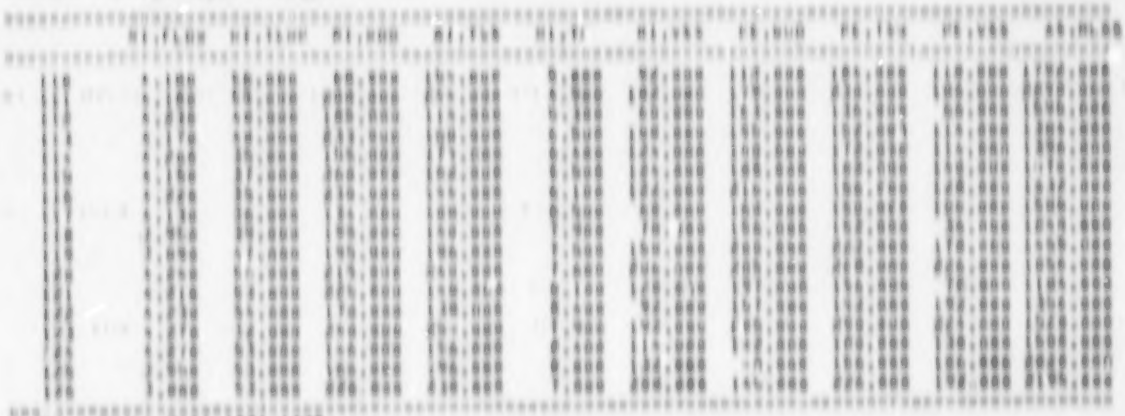
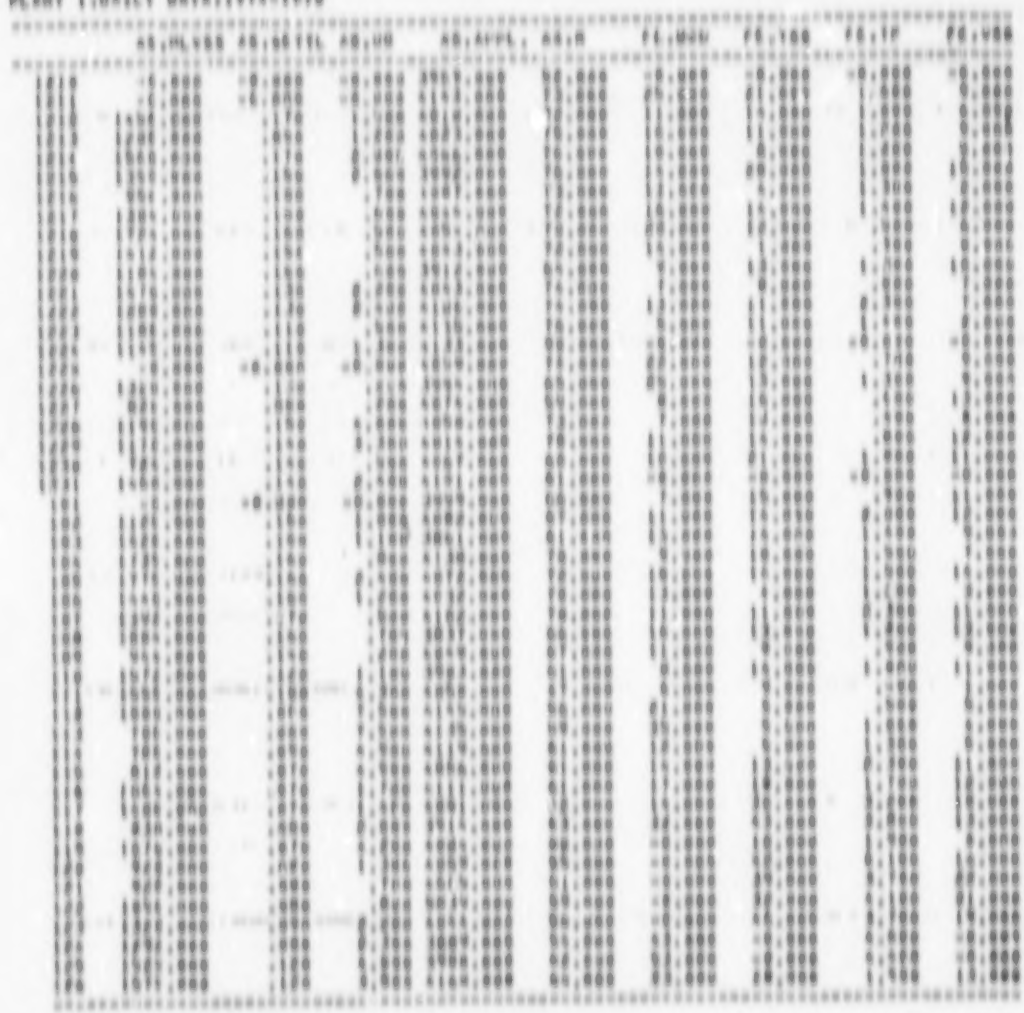
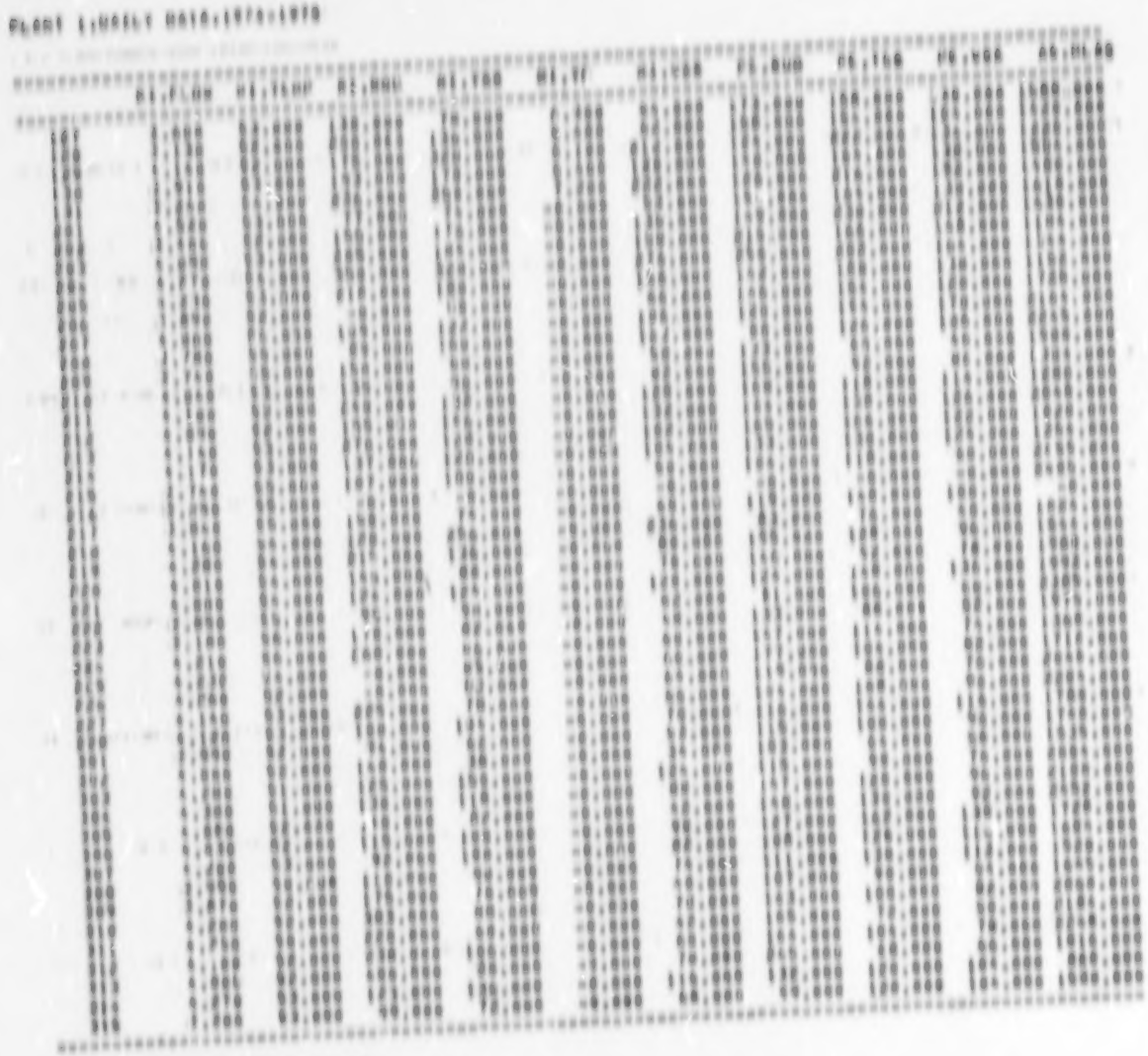
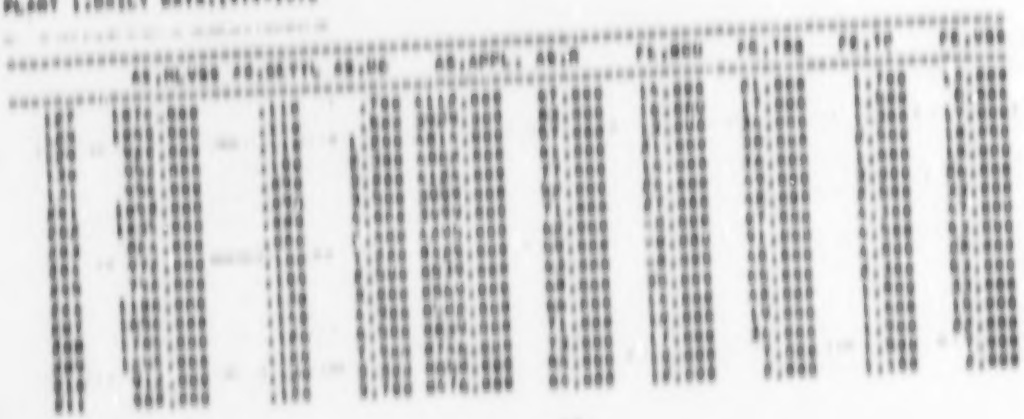


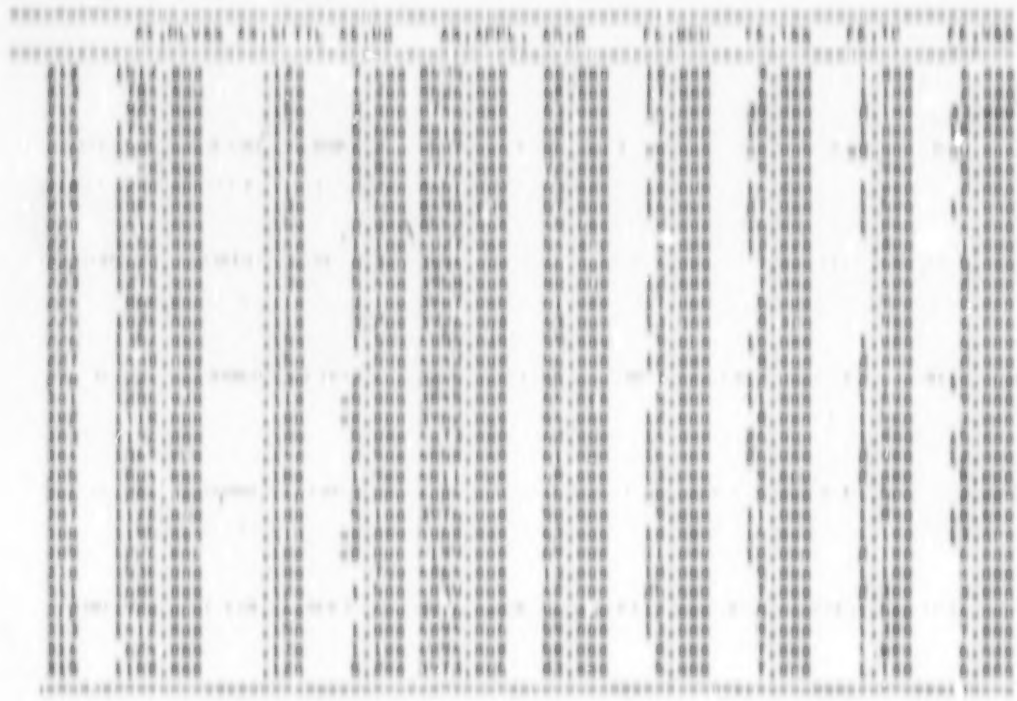
PLANT 1:DAILY DATA:1974-1978



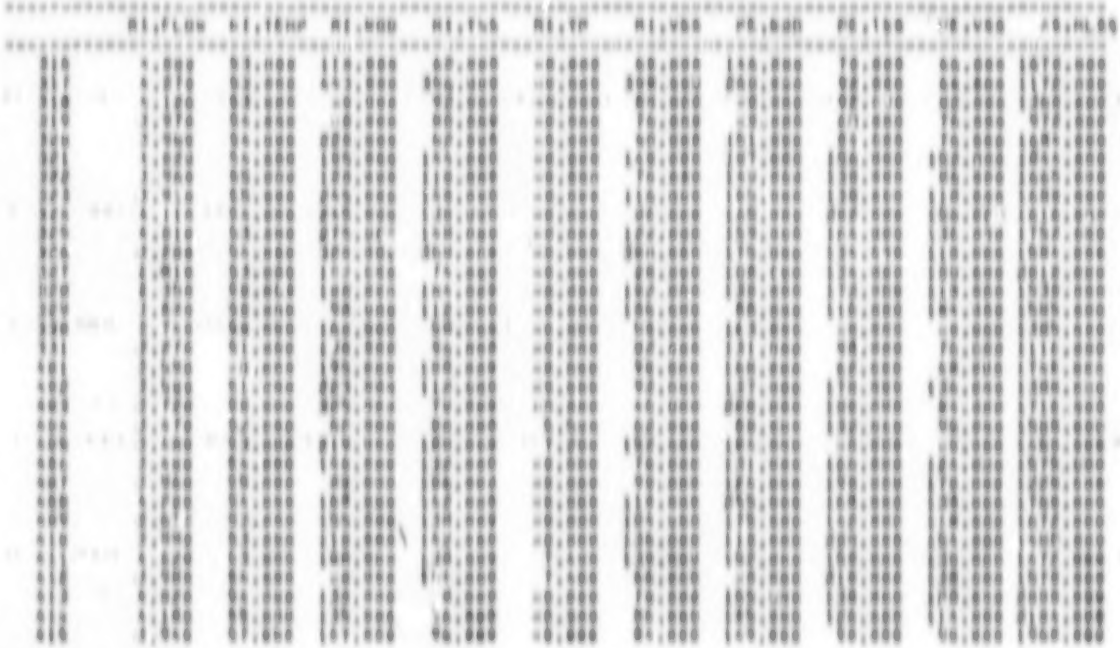




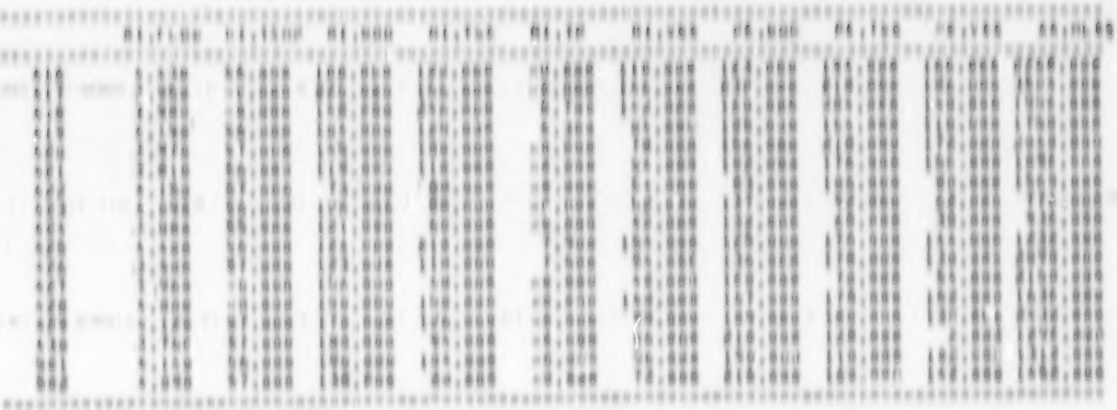
PLANT 1:DAILY DATA:1976-1979



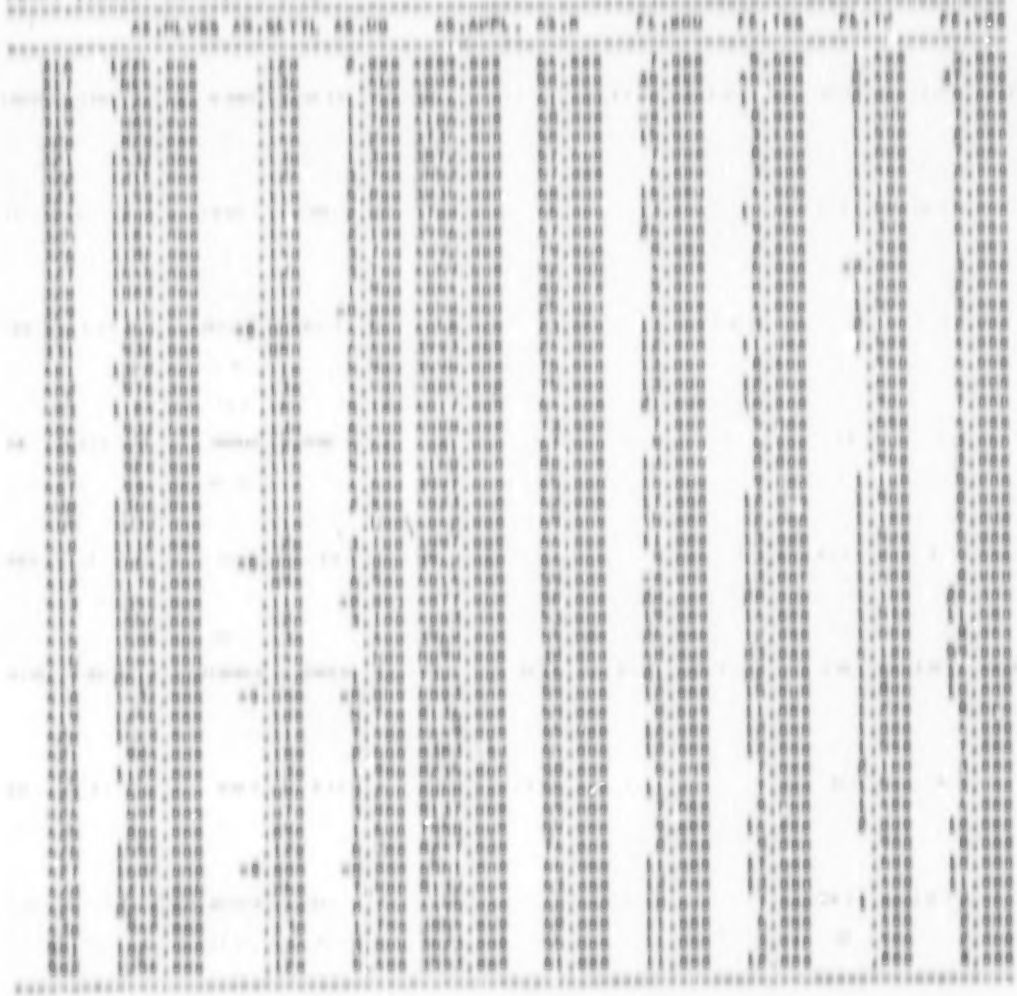
PLANT 1:DAILY DATA:1976-1979



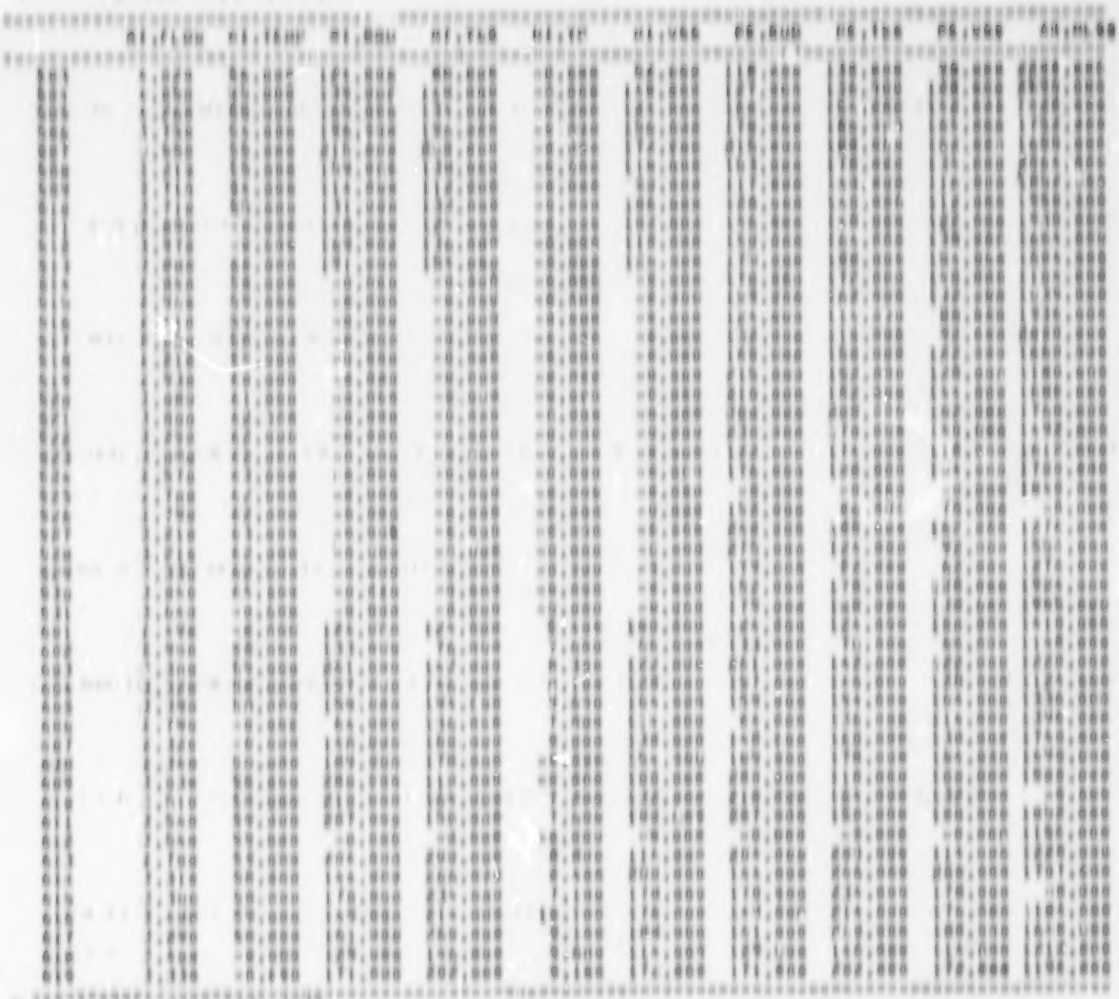
PLANT 1:DAILY DATA:1975-1979



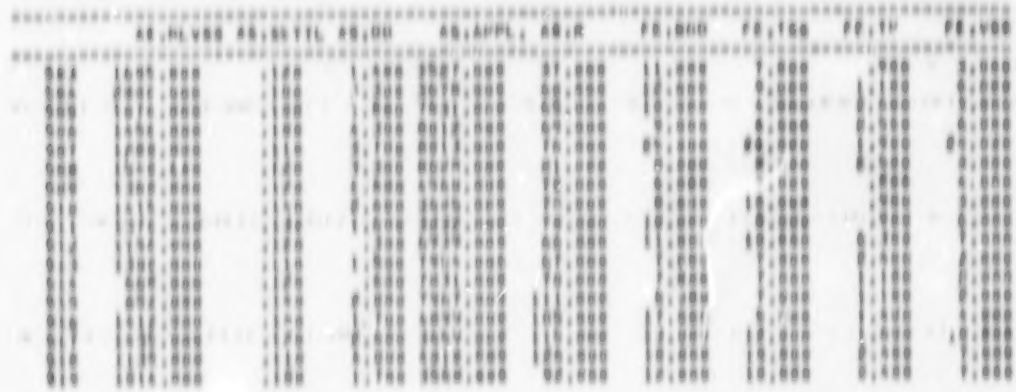
PLANT 1:DAILY DATA:1975-1979



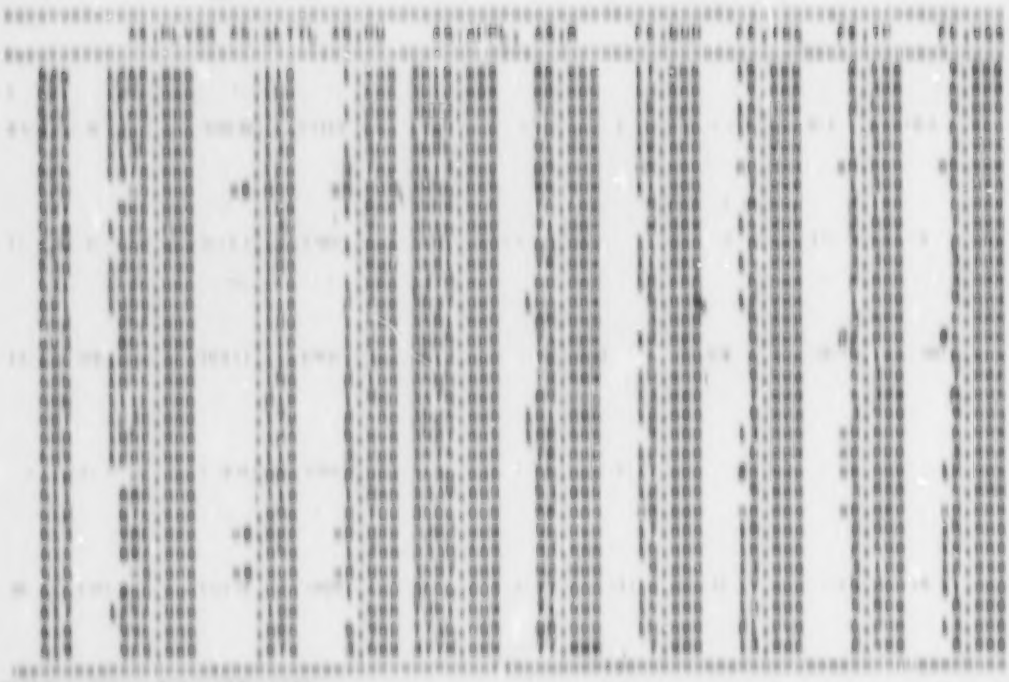
PLANT A:DAILY DATA:1974-1979



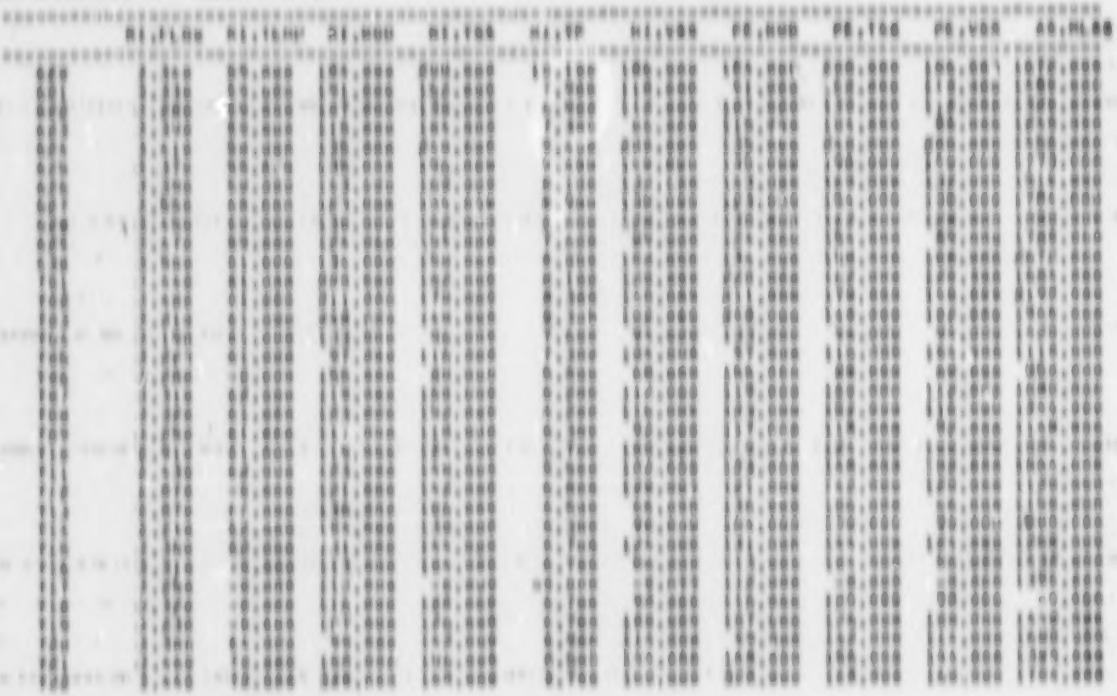
PLANT B:DAILY DATA:1974-1979



PLANT 1:WEEKLY DATA:1976-1979



PLANT 1:WEEKLY DATA:1976-1979



PLANT A:MONTHLY DATA:1974-1978

PLANT A:MONTHLY DATA:1974-1978